

THE BILIARY TRACT OF CERTAIN RODENTS WITH AND THOSE WITHOUT A GALL BLADDER ¹

GEORGE M. HIGGINS

*Division of Experimental Surgery and Pathology, The Mayo Foundation,
Rochester, Minnesota*

FOURTEEN FIGURES

In spite of valuable work during the last few years on the physiology of the gall bladder, its entire function in the economy of the organism remains relatively obscure. Many explanations of its function or functions have been advanced, but none is wholly satisfactory. Certain it is that its function appears relatively insignificant as concerns the organism as a whole. Its complete extirpation, whether for clinical or experimental reasons, is apparently without deleterious effect on the general well-being of the individual. On the other hand, there is no doubt that the gall bladder has a physiologic significance. The main facts proving this are the dilatation of the extrahepatic ducts following its extirpation(1); the earlier appearance of bile pigment in the blood (the common bile duct being occluded) when the gall bladder is removed than when it is left intact(3); and the fact that the bile which reaches the gall bladder is concentrated about ten times by the absorptive activity of the viscus(5).

The problem of the gall bladder is further complicated by the normal absence of the vesicle in many species representative of groups which normally possess one. Thus it is absent in the case of the horse, present in the pig, absent in the elk and deer, but present in the cow, sheep, and goat. It is present in the hawk, but not in the pigeon or parrot. Likewise it is found in the mouse, but absent in the rat and in the

¹ Submitted for publication September 24, 1925.

pocket-gopher. No considerable data have ever been presented which will explain why certain animals do not have gall bladders, although many hypotheses have been proposed. And further, a compensating mechanism has never been described which could explain the absence of the vesicle in any particular species. It is difficult to see how the presence or absence of the vesicle could depend on the nature of the food, for, in the animals cited, the vital processes appear to be sustained equally well on corresponding diets. That the food relations of the ancestors could have been a factor seems also untenable, for it is improbable that the ancestral herbivores developed on divergent diets. Herbivorous mammals vary, and even rumination is not a determining cause, since some ruminant species and not others have gall bladders. In the case of the mouse and the rat, environmental factors are relatively similar. Both are rodents and pursue in a measure the same general habits of life. Why one should possess a gall bladder and the other lack it is a problem of great physiologic and morphologic interest. The similarity of environment and food suggests that those animals normally lacking a gall bladder possess some mechanism which compensates for the absence of the vesicle. In some cases the relative size and length of the bile duct in animals lacking a gall bladder were found to be greater. With more evidence, however, this factor was considered negligible. At least from the standpoint of extrahepatic relations there appears to be no compensatory morphogenesis. Physiologically, it has been shown that(2), at least as far as the bile-concentrating function of the vesicle may go, those animals which lack a gall bladder do not appear to possess its physiologic equivalent, for obstruction of the ductus choledochus in the rat shows that stasis bile is never more concentrated in pigment than it is normally.

In the absence of any extrahepatic compensating mechanism in the rat, the question of the existence of an intrahepatic one led to these studies on the differences that may exist between the developing biliary tracts of the white mouse and the

white rat. These animals were chosen for study not only because of their availability, but also because of their familial and ecologic relationships.

No comparative analysis of the entire development of the complete biliary apparatus in two such closely allied types is available. The literature includes many valuable treatises on the development of the liver in various animals, but no attempt is made here to review them. Scammon(6) reported the early development of the liver, the ducts of the liver and the gall bladder in the elasmobranch fishes. Later, in 1916, Scammon presented an interesting comparative study on the development of the biliary system in certain animals lacking the gall bladder in adult life. He reported on the developmental processes in *Petromyzon*, the pigeon, and the rat. In all, his observations were restricted to the potential gall-bladder region and do not concern the remaining portions of the biliary apparatus. Mann, Brimhall, and Foster(4) reported their observations on the length of the common duct in animals with and without a gall bladder, but were unable to recognize any reliable extrahepatic factor that could compensate for the absence of the vesicle in any animal. Likewise, they could find no common factor on the basis of the anatomic relationship of the opening of the ductus choledochus to the duodenum in animals with or without a gall bladder.

In these studies no attempt has been made to secure the embryo of either the mouse or the rat in its very early stages. Reliable data are available regarding the origin of the hepatic diverticulum in mammals and its differentiation into the vesicular and hepatic portions. Scammon(7) carefully examined early rat embryos of The Wistar Institute collection, and concluded that a gall bladder as such was not present at any time. He recognized, however, the division of the diverticulum of the liver into two parts, an anterior and a posterior, and along the ventral wall of the latter he recognized a small depression which was analyzed as the remnant or vestige of the normal gall bladder. This depres-

sion, lined with typical columnar epithelium, is only transitory and disappears during the early period of development. The anterior portion of the original diverticulum becomes the pars hepatica and produces the hepatic trabeculae and hepatic ducts, the further growth and differentiation of which this study attempts to analyze.

Early embryos were taken from the gravid uterus of the mouse and the rat at intervals, under sterile technic, so that in most cases the embryos of each species studied had a common parentage. Those taken in the earliest stages measured 4 mm. crown-rump length, and successive ages were secured up to and including that at birth. The embryos were all fixed in Zenker's fluid and stained in either hematoxylin and eosin or hematoxylin and acid fuchsin. The younger embryos were cut into sections 5μ thick, while the older ones were sectioned at 8 and 10μ . In order fully to appreciate the distribution of the hepatic ducts and their relation to the substance of the liver, wax reconstructions were made of those stages most instructive in the developmental process.

In the earliest mouse embryo, 4.2 mm. long, with which these observations begin, the distal portion of the original hepatic diverticulum has already formed a greatly enlarged vesicle which is to differentiate into the cystic duct and gall bladder. One is impressed by the size of this structure as compared to that of the other organs, it being greater in diameter by far than the duodenum which lies beneath it (fig. 1). It already possesses a partial lumen, although it is not entirely hollow until a later stage, when it appears to become distended with bile. The vesicle is surrounded by an area of mesenchyme cells, although differentiation into its respective layers is not yet evident. The proximal portion of the original diverticulum continues rather broadly with the duodenum at its point of origin. This is potentially the common bile duct together with the hepatic ducts which grow from it into the liver substance, although at this stage the ducts are not yet evident. There occurs, however, a single median sprout, from the junction of the common duct with

the vesicular anlage, which is to become the first hepatic duct. This sprout is without a lumen, and from it numerous cells independently bud, to form the liver trabeculae around the sinusoidal spaces. Likewise, hepatic cells appear to arise from the region of the cystic duct as well as from the common duct and form cords of cells which become hepatic trabeculae. As in mammals generally, the dorsal and ventral pancreatic lobes are present and bear the normal relationship to the duodenum and hepatic diverticulum, so that in this stage a well-defined pancreatic duct empties into the common duct near its intestinal connection.

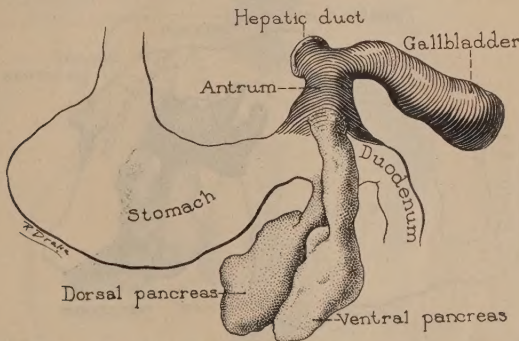


Fig. 1. Reconstruction of the biliary tract of a mouse 4.2 mm. long.

In the 4-mm. rat embryo no structure could be identified which could be homologized with the distal portion of the hepatic diverticulum in the mouse. Nor, with certainty, could the depression described by Scammon be identified at this stage. So a gall bladder, either potential or complete, could not be recognized at this or at any other stage. Just what factors are involved to preclude the development of the distal portion of the diverticulum into a vesica fellea is as yet only a conjecture. On the other hand, the homologue of the proximal portion of the diverticulum in the mouse is entirely evident in this stage of the rat, and the two pancreatic lobes and the anlage of the ductus choledochus are present, as well

as numerous small solid buds or outgrowths, the beginning of the hepatic ducts (fig. 2). Thus far, then, considerable similarity exists in these animals as concerns the proximal part of the diverticulum. Attention is called to the contrast, however, that in the mouse a single median hepatic sprout first appears, while in the rat several small outgrowths characterize the hepatic anlage at this stage. It is evident, then, that in this early rat embryo no morphologic equivalent of the gall bladder exists, and if there is any physiologic equivalent, it is not as yet evident. However, it is improbable that biliary function has begun, although lobes of the liver and vascular

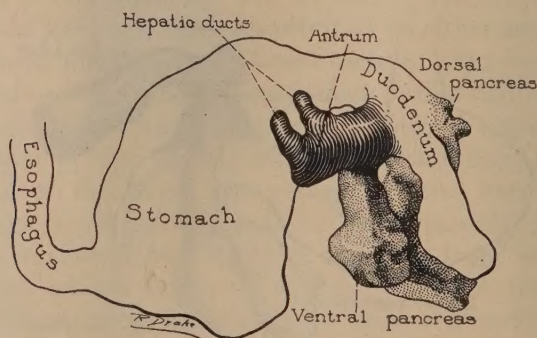


Fig. 2 Reconstruction of the biliary tract of a rat 4 mm. long.

sinusoids are well advanced. In subsequent growth, with the secretion of bile, some compensatory mechanism may appear to discharge the normal function of the gall bladder.

In a 6.4-mm. mouse embryo, the fundus of the vesicle is somewhat larger and the typical vesicular columnar epithelium is more apparent. The cystic duct remains essentially unchanged and continues into the hepatic antrum² from which a pair of hepatic ducts now lead. This antrum is now broader, somewhat crescent-shaped, and besides the median hepatic sprout a pair of lateral hepatic outgrowths extend but a short

² The term 'hepatic antrum' was first used by Dr. E. A. Boyden in a paper as yet unpublished to designate an embryonic vestibule into which all the ducts of the liver, including the cystic duct, empty. It is of transitory existence only.

distance into the liver substance. The lumen is only partially complete at this time. From the ends of the outgrowths cells continue to bud forth, forming additional liver trabeculae. At the 7-mm. stage, two additional hepatic ducts have appeared (fig. 3). These arise from the antrum distal

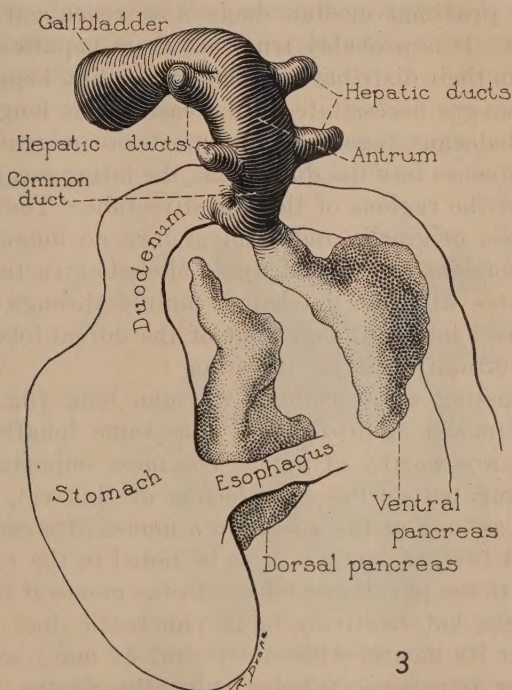


Fig. 3 Reconstruction of the biliary tract of a mouse 7 mm. long.

to the pair already described and likewise extend laterally toward the lobes of the liver. These are also only partially canalized and, as the others, give rise to cells potentially hepatic. Thus the biliary apparatus of a 7-mm. mouse consists of a globular vesicle, a cystic duct, an antrum into which lead the five short hepatic ducts, and a relatively short ductus choledochus. An embryo 8.5 mm. long is characterized by

a greater longitudinal growth of the cystic duct together with certain other changes. The liver substance has greatly increased in extent and now practically encases the biliary apparatus together with related parts of the alimentary tract. Additional proliferation of cells from the hepatic antrum has now formed new hepatic ducts, so that, besides the others, distal and proximal median ducts now reach out into the liver tissue. It is probably true that these hepatic ducts are restricted in their distribution to corresponding hepatic lobes. Further changes necessitate an increase in the length of the ductus choledochus, together with a posterior migration of its point of entrance into the duodenum, the latter occasioned by a growth of the regions of the digestive tube. The two pancreatic lobes, originally independent, are no longer so, but have now combined to form a single bilobate structure, which communicates with the duodenum mainly through the duct of the ventral lobe, although that of the dorsal lobe still retains its continuity with the intestine.

In contrasting a rat embryo 8.4 mm. long (fig. 4) with the young mouse approximately the same length, several differences are worthy of note. The most important is the greatly elongated ductus choledochus of this rat, which is four times as long as the ductus in a mouse of a corresponding age. A further contrast is to be noted in the relation of the ductus to the pancreatic lobes. In the mouse it is recalled that a single, but relatively large pancreatic duct joins the ductus near its mouth, while in the rat as many as four or five smaller pancreatic tubules enter the ductus from the combined dorsal and ventral lobes. The original duct of the dorsal pancreatic lobe is not present at this stage. The distal portion of the original hepatic diverticulum, which was but faintly evident in the earlier rat embryo, now forms an antrum of considerable size into which numerous hepatic ducts lead. There seems to be no particular order or arrangement in the origin of these hepatic ducts from the antrum. It is recalled that in the mouse paired lateral diverticula appear to arise in conjunction with a median one in a rather definite way,

while at this stage in the rat seven distinct hepatic ducts lead from various parts of the antrum out into the liver substance. As in the case of the mouse, however, these ducts are canalized for a short distance only, and from their solid ends scattered cells bud off to form additional liver trabeculae. At this stage there seems to be no particular relation between the hepatic ducts and the portal vein and its branches, but in later embryonic stages the relations of the two systems warrant careful consideration.

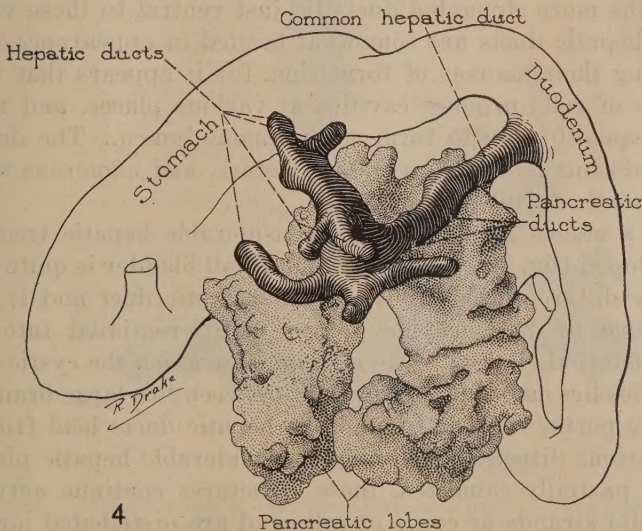


Fig. 4 Reconstruction of the biliary tract of a rat 8.4 mm. long.

In a 12-mm. mouse embryo greater proportions are attained in all regions of the biliary apparatus. The antrum is distinctly triangular in outline, and into it now lead a larger number of hepatic ducts which reach farther into the liver substance; and, also, hepatic cells continue to bud from them, forming additional trabeculae. The arrangement of the ducts shows no particular relation to the antrum, the original symmetric order having disappeared. In contrast, in a rat em-

bryo of an approximately corresponding age, a difference is noted in the general appearance and in the vascularity of the tissue of the liver. In the rat the tissue is far less compact, the cells are more loosely arranged, and the vascular sinusoids are more numerous and even larger than in the mouse. Then, too, the hepatic ducts leading from the antrum are more numerous, and they appear to be somewhat more closely related to the larger vascular channels in the liver. The position of the antrum in respect to the larger portal branches is much the same in both embryos, and yet, in the rat, the more elongated ducts lie just ventral to these veins. The hepatic ducts are somewhat beaded in appearance, suggesting their manner of formation, for it appears that solid cords of cells produce cavities at various places, and these subsequently join to form a continuous lumen. The ductus choledochus is even longer than before, and numerous small pancreatic ductules lead into it.

In a mouse 15 mm. long, a considerable hepatic tree has developed (fig. 5). A large globular gall bladder is quite definitely differentiated from a smaller cystic duct and is surrounded by mesenchyme as yet undifferentiated into the characteristic layers. The antrum into which the cystic duct empties lies embedded in the liver between two large branches of the portal vein, and numerous hepatic ducts lead from it in various directions, forming a considerable hepatic plexus. Only partially canalized, these structures continue outward as solid strands or cords of cells and are distributed largely around the branches of the portal vein, as well as into the tissue of the liver. By way of further contrast, the antrum of a young rat, 16 mm. long, of an approximately corresponding age, is relatively much larger, but lies similarly between two larger branches of the portal vein. From this numerous ducts may be followed, and these appear literally to encircle the branches of this vein (fig. 6). This condition is not unlike that observed in the mouse, and yet the greater extent of the intrahepatic biliary apparatus of the rat at this stage is striking. In diameter the antrum is twice as large as the

gall bladder of the mouse of corresponding age, so that one wonders whether the first evidence of a compensatory growth in the absence of the gall bladder is not presented at this point. In an older rat embryo, 20 or 22 mm. long, the extent of this intrahepatic biliary apparatus is all the more pronounced. From the large antrum, described in earlier stages, additional ducts now lead out to join those already present, so that now a more or less complete plexus of hepatic channels encircles the main branches of the portal system. The

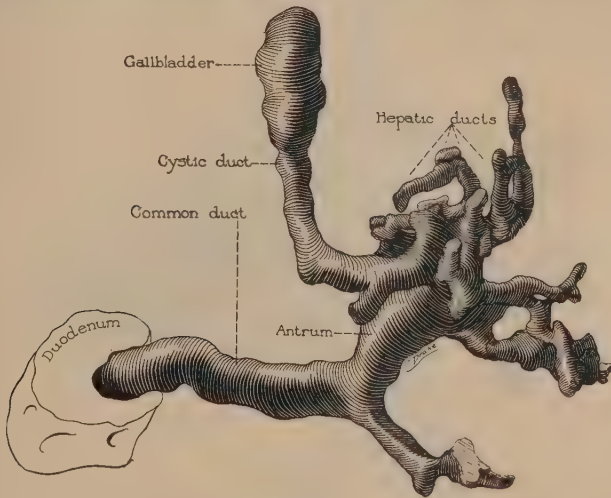


Fig. 5 Reconstruction of the biliary tract of a mouse 15 mm. long.

hepatic tubules follow the vascular channels as they branch and the two systems seem closely allied to each other. So extensive is the plexus of hepatic tubules around the vascular channels, that it frequently appears as a greatly extended cavity around them (fig. 7). Of interest, too, is the distinct columnar epithelium which forms the antrum, resembling therein the mucosal lining of the normal gall bladder of the corresponding mouse.

Whether the more open structure of parenchyma and trabeculae and the greater vascularity in the liver of the rat have

any particular significance is yet to be considered. Numerous pancreatic ducts enter the ductus choledochus as it passes through the pancreas to the duodenum.

Later stages of both mouse and rat embryos were examined histologically for further evidence of this intimate relationship between the intrahepatic biliary system and the portal vein. In each embryo examined, a more extensive development of the small hepatic ducts around the portal vein characterized the rat, although a much smaller plexus was found in the mouse. Other than that, no particular distinction between the two animals was evident.

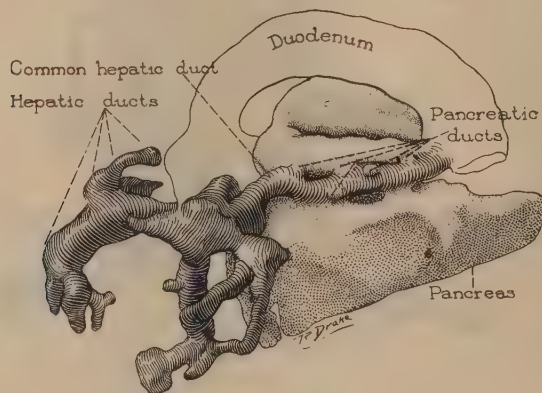


Fig. 6 Reconstruction of the biliary tract of a rat 16 mm. long.

To determine whether or not this plexus of hepatic channels characterized the adult, India ink was injected into the common hepatic ducts of full-grown mice and rats. There is no difficulty in distending the entire system, as the ink readily mixes with the bile content and can readily be forced into the ultimate lobules. Thereafter, by dissection, or by fixation and sectioning, the distribution of the hepatic tree can readily be followed. Numerous rats and mice were thus injected and the observations here recorded were made largely on gross dissection following fixation in formalin. Bearing out the results of the observations on the younger

animals, the adults, following injection, showed this same relationship. The antrum, described as an embryonic structure, no longer exists, but is now incorporated into the elongated duct system. In both the adult rat and mouse, two rather large hepatic ducts accompany each main branch of the portal vein through the lobes of the liver, while usually but a single one follows the smaller distal branches of the vein.

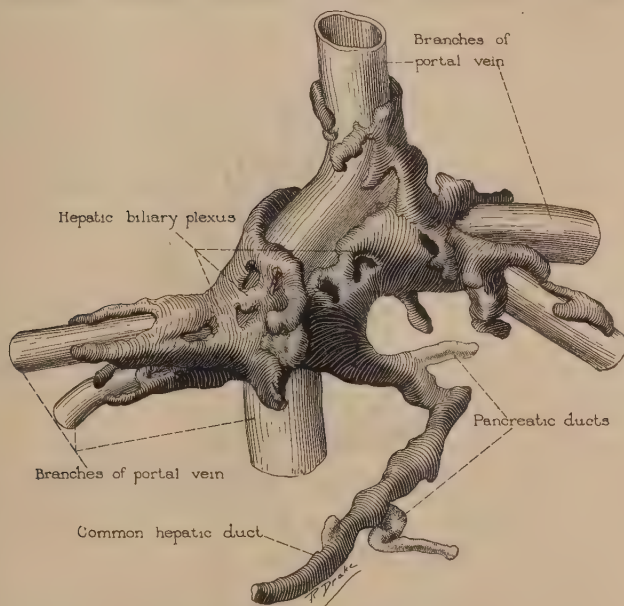


Fig. 7 Reconstruction of the biliary tract of a rat 22 mm. long.

Bile ducts were never found to be associated with any portion of the hepatic veins in either the mouse or the rat. But the interesting contrast, that which is foreshadowed by the embryonic conditions, is strikingly evident in the adult. The hepatic plexus around the portal vein is an anatomic characteristic of the adult rat (figs. 9, 11, 12, and 14). From the paired hepatic biliary channels lying adjacent to the vein, numerous smaller ducts extend around it and form an exten

sive greatly branched hepatic plexus (fig. 12). In the mouse, on the other hand (figs. 8, 10, and 13), whereas numerous branches arise from the elongated bile ducts which parallel the vein and in some cases do extend around the vein, no such extensive plexus could be identified which might compare with that described for the rat. This plexus in the rat is not restricted to the proximal portions of the venous branches, but continues distally onto the smaller veins as well (fig. 12).

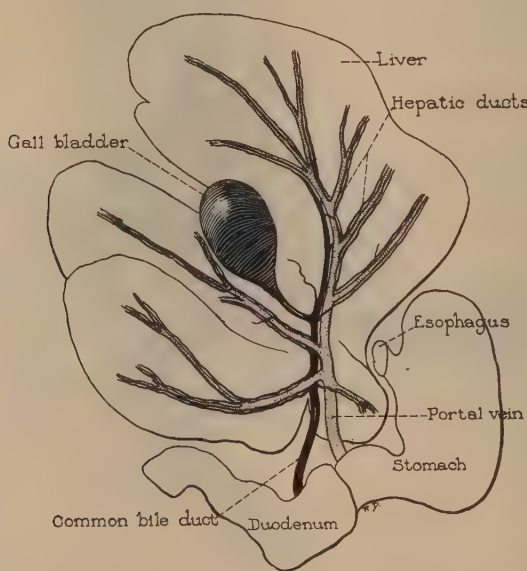


Fig. 8 Diagram of a dissection of the liver of an adult mouse.

DISCUSSION

So far as these observations are concerned, the rat lacks a gall bladder throughout its entire life. The distal portion of the original hepatic diverticulum, which in many other animals becomes a functioning vesicle, could not be identified in any of the early stages of development, while the differentiation of the proximal portion is more or less the same in both the mouse and the rat. Although there may be indi-

vidual differences in the two, yet in both animals, this proximal portion becomes the common duct, the antrum, and the hepatic ducts. The term antrum is used to designate that region of the embryonic biliary apparatus from which the hepatic ducts grow toward and into the liver tissue. In the mouse there appeared to be some sequence in the way these hepatic ducts arise; but in the rat, no particular order of

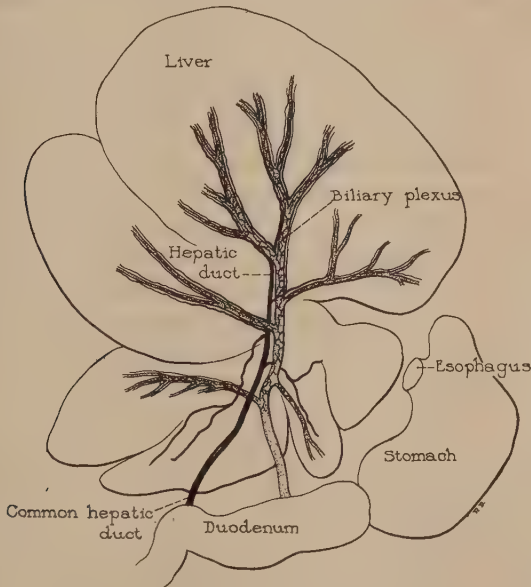


Fig. 9 Diagram of a dissection of the liver of an adult rat.

appearance could be noted. In the later embryonic periods, however, all sequence or order has disappeared and numerous ducts extend out from a now somewhat elongated antrum, into the respective lobes of the liver. At first solid, these outgrowths are gradually canalized and become the functional hepatic ducts. No attempt was made to follow the growth of any duct into its component branches to the ultimate hepatic lobule and the terminal canaliculi; numerous histologic texts present adequate data concerning this relationship to the

hepatic trabeculae. But the attempt was made to determine what differences, if any, exist between the distribution of the biliary tracts in the two species.

During the early embryonic development there appeared to be no particular relation between the developing biliary apparatus and the vascular channels. Subsequently, however, with the appearance of a localized antrum, a more definite positional relationship arose between the two tissues. As the vena portae arises from the primitive vitelline veins, its intrahepatic portion comes to lie directly dorsal to the biliary antrum, so that the earliest hepatic ducts develop relatively near this vascular channel. This relationship is true for both the mouse and the rat, but as more ducts arise and develop more extensively, the relationship between biliary ducts and the vascular channel becomes far more pronounced. This subsequent development is more evident in the later rat embryo than in the mouse, although in the latter animal a more or less intimate relationship exists between these structures. In rat embryos measuring from 22 to 25 mm. the extent to which the biliary ducts encircle the branches of the portal vein is so marked that the hepatic ducts appear to form an enlarged plexus of channels around the veins; at the branching of the veins, the main hepatic plexus continues distally to form smaller plexuses around the smaller branches of the portal vein. Although the later mouse embryos were found to possess some such intimate appositional relations between the biliary and the portal channels, yet the degree of this relationship was relatively much less pronounced. Herein, then, was observed a morphologic contrast that appeared worthy of note and further study.

In later embryonic stages of both the rat and the mouse, the foregoing relationship continued to exist, but was always more pronounced in the young rats. The question arose as to whether this association of the biliary and vascular channels could explain the absence of the gall bladder. To determine whether or not this differentiation was apparent in the adults of these animals also, the common hepatic ducts of

both rats and mice were injected with an India-ink solution. The ink mixes readily with the contained bile, so that the most minute capillaries and canaliculi may be readily followed to the distal parts of the liver. On gross dissection, it is evident that the intimate association between the biliary and vascular tissues persists. It is a long-recognized fact that the bile ducts usually follow the course of the portal vein and its branches; but so far as I am aware, a highly specialized plexus of smaller bile ducts, such as exists around the portal vascular tree in the rat, has not been hitherto described. The main branches of the portal vein are flanked on each side by a bile duct, while, from these two, numerous smaller ducts continue over the outer coat of the vein. Intimate and extensive branching of these smaller bile ducts has resulted in the formation of an extensive plexus around the portal vein and its branches. By way of contrast, the injected biliary tracts of the mouse fail to reveal any similar plexus. True, the portal vein and its branches are paralleled by bile ducts, as in the rat; but so extensive a plexus of bile ducts around the veins does not exist.

This study has thus indicated that the only points of difference between the biliary tracts of these animals, other than that of size, are the presence of the gall bladder in the mouse and the presence of an extensive, branching hepatic plexus around the branches of the portal vein in the rat. From the morphologic standpoint, it would seem highly probable that the latter structure may serve a physiologic purpose in the rat, similar to that of the gall bladder in the mouse.

An excellent illustration of how this intrahepatic mechanism may function in lieu of a gall bladder is obtained by a consideration of the data concerning one of the known activities of the gall bladder, that is, the concentration of the bile entering it.

The concentrations of bile pigment in bile taken from the different lobes of the liver of the dog are approximately constant; whereas that taken from the gall bladder at the same time shows a bilirubin content ten or twelve times as great (5).

Likewise, on ligation of the common duct proximal to its junction with the hepatic ducts, the subsequent bile in the ductus choledochus shows a far higher concentration of bilirubin than the normal(5). This is further evidence of the concentrating mechanism of the gall bladder. Furthermore, if the common bile duct is obstructed in a dog and the gall bladder left intact, bilirubin can hardly be detected in the serum by the van den Bergh test at the end of twenty-four hours; whereas if the gall bladder is excised at the same time that the common bile duct is obstructed, bilirubin can be detected in the serum three hours after operation(3).

Thus, at least a bile-concentrating activity of the gall bladder seems well established. Just why the organism needs concentrated bile, or just what function concentrated bile discharges in the economy of life, is not understood. If concentration is essential, then it would follow that animals that normally lack gall bladders must possess compensating mechanisms elsewhere. Existing data suggest that this is true. The concentration of bile in the hepatic ducts and the gall bladder of the albino mouse and rat have been studied. As was true for other animals that possess a biliary vesicle, bladder bile of the mouse shows a higher bilirubin content than that collected from the common duct of the same animal(5). Then, too, stasis bile of the common duct in dogs with an intact gall bladder shows a large increase in pigment content; but, on the other hand, ligation of the common hepatic duct in the rat does not induce any increase in the concentration of pigment(2). In other words, the rat does not possess any concentrating mechanism in the extrahepatic ducts which is analogous to that of the normal gall bladder. It is to be noted, however, that the bilirubin concentration of the bile taken from the common hepatic duct in the rat is eight times as great as that from the liver of the mouse(5). Thus it would appear that, if a mechanism for bilirubin concentration does exist in the rat, it must be an intrahepatic one, for this function is already discharged before the bile enters the common hepatic duct. Accordingly, at least the physiologic equivalent

of the gall bladder must be present in those species which have no gall bladder, but in which the pigment shows a high concentration of the bile. In the mouse the bile, subjected to the concentrating activity of the gall bladder, eventually shows a bilirubin content not unlike that of the rat; so that, in all probability, the concentration of the bile delivered to the duodenum is relatively equal in the two animals. Since the stasis bile of the rat, unlike that of the mouse, never undergoes the color changes from yellow to green or dark brown, but invariably retains its yellow hue and normal concentration of pigment, it would appear that practically no change, if any, occurs in rat's bile following its passage from the liver. It is suggested, therefore, that the actual concentration of the bile in the rat may be caused by the action of the hepatic plexus around the branches of the portal vein.

SUMMARY

The morphogenesis of the biliary tracts in the white mouse and the white rat was studied.

The gall bladder develops relatively early in the embryonic life of the mouse. In a 4.2-mm. embryo it is partially canalized and is relatively large, exceeding in diameter that of the adjacent duodenum.

A gall bladder, or even vestige of one, was never identified in any ontogenetic stage of the rat.

The hepatic ducts grow out from the antrum of the biliary diverticulum into the tissue of the liver. In the embryos of both the rat and the mouse certain of these ducts become associated with the embryonic vascular channels at an early stage.

The association between the hepatic ducts and the vascular channels is much more pronounced in rat embryos than in young mice.

In a 22-mm. rat embryo hepatic ducts form a considerable plexus around the branches of the portal vein.

In the mouse a pair of biliary channels follows the branches of the portal vein to the ultimate lobule.

Besides these hepatic channels, an extensive plexus of small biliary ducts passes around the branches of the portal vein in the rat. These smaller ducts are connected with the larger bile ducts which parallel the vein.

The mouse's liver does not possess so extensive a plexus of bile ducts around the vascular channels.

Other than the extent of the biliary tract and the presence of the vesicle in the mouse, no difference between the biliary tracts of these rodents exists other than the presence of the biliary plexus around the portal vein in the rat.

This plexus of bile ducts around the portal vein in the rat's liver may be an intrahepatic compensatory mechanism for the concentration of bile or for other functions analogous to those of the gall bladder of the mouse.

BIBLIOGRAPHY

- 1 JUDD, E. S., AND MANN, F. C. 1917 The effect of removal of the gallbladder. *Surg., Gynec. and Obst.*, vol. 25, pp. 437-442.
- 2 McMASTER, P. D. 1922 Do species lacking a gall bladder possess its functional equivalent? *Jour. Exp. Med.*, vol. 35, pp. 127-140.
- 3 MANN, F. C., AND BOLLMAN, J. L. 1925 The relation of the gallbladder to the development of jaundice following obstruction of the common bile duct. *Jour. Lab. and Clin. Med.*, vol. 10, pp. 540-543.
- 4 MANN, F. C., BRIMHALL, S. D., AND FOSTER, J. P. 1920 The extrahepatic biliary tract in common domestic and laboratory animals. *Anat. Rec.*, vol. 18, pp. 47-66.
- 5 ROUS, P. C., AND McMASTER, P. D. 1921 The concentrating activity of the gallbladder. *Jour. Exper. Med.*, vol. 34, pp. 47-74.
- 6 SCAMMON, R. E. 1912 The development of the Elasmobranch liver. *Am. Jour. Anat.*, vol. 14, pp. 333-410.
- 7 ———— 1916 On the development of the biliary system in animals lacking a gallbladder in postnatal life. *Anat. Rec.*, vol. 10, pp. 543-558.

PLATE 1

EXPLANATION OF FIGURES

- 10 Photograph of a dissection of the liver of an adult mouse.
- 11 Photograph of a dissection of the liver of an adult rat.

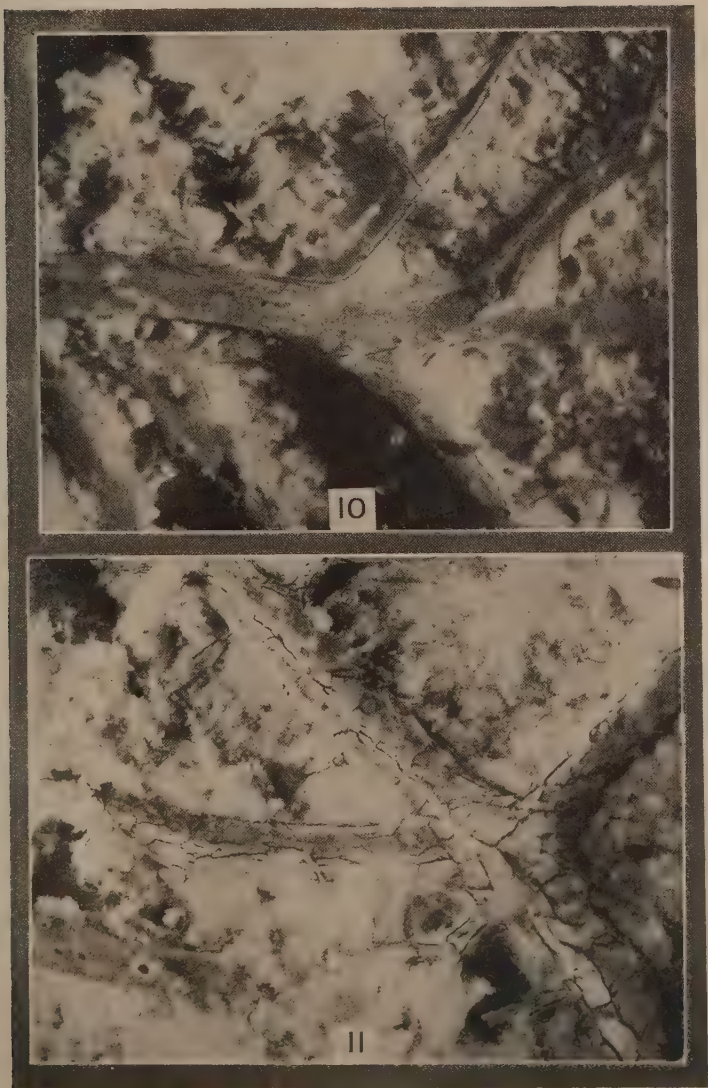


PLATE 2

EXPLANATION OF FIGURES

12 Photomicrograph of a section of the liver of an adult rat, including a small branch of the portal vein and the extensive biliary plexus around it.

13 Photomicrograph of a section of the liver of an adult mouse, including a small branch of the portal vein and a single bile duct.

14 Photograph of a reconstruction of the intrahepatic biliary plexus and a branch of the portal vein in the adult rat. $\times 66$.



ON THE TESTIS AND ITS ACCESSORY STRUCTURES IN THE PORPOISE

CHI PING

*Department of Biology, Agricultural College, Southeastern University,
Nanking, China*

TWO FIGURES

The porpoise whose testis and related structures are described herewith is *Neomeris phocaenoides*, caught in the Yangtse River by Prof. H. C. McCloy, of the Southeastern University. As far as I can discover, the morphology of the male reproductive glands and their ducts in this animal has not been investigated heretofore, and therefore it is deemed wise to present the following notes, which represent the results of my observations on them. I desire to thank Mr. McCloy for presenting me with the material.

TESTIS

The testes are attached to the dorsal body wall latero-caudal to the kidneys. Each is flattened and reniform, measuring 150 mm. long, 75 mm. wide, and 25 mm. thick. The tunica vaginalis is smooth and grayish in color in the preserved specimen, continuing over its dorsal side to cover the epididymis, where it appears wrinkled on account of the convolutions of the latter, while the tunica albuginea covers the glandular part of the organ. There is no cavity of the tunica vaginalis, as the latter membrane and the tunica albuginea are closely fused together. The tunica albuginea is thick and tough, its average thickness measuring about 1 mm. On removing the tunica albuginea, the surface of the gland appears, in the usual manner, to consist of many irregular areas which represent the external surfaces of the lobules

bounded by septal membranes (fig. 1), but the number of these areas is by far greater than that found in an ordinary mammalian testis. The septa between the lobules are deli-

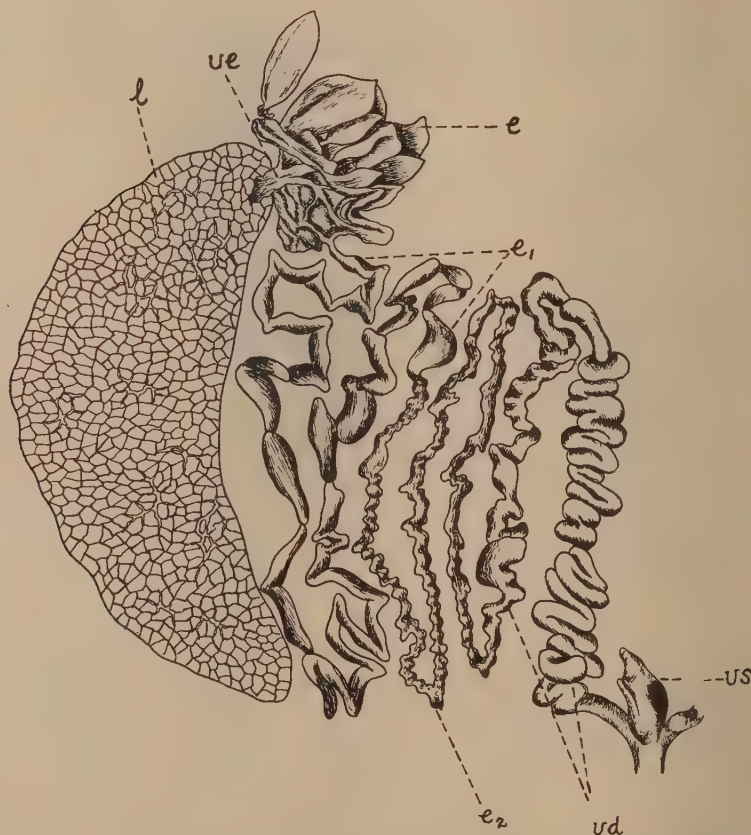


Fig. 1 Right testis with tunica albuginea removed and sperm duct more or less unraveled. *e*, head of epididymis; *e*₁, body of epididymis; *e*₂, tail of epididymis; *l*, lobules; *vd*, vas deferens; *ve*, vas efferens; *vs*, vesicula seminalis.

cate, but they are thickened at various regions, especially at their attachments to the internal surface of the tunica albuginea. The shape of each lobule is very irregular, and of how many tubules each consists I have not been able to determine.

In many places in the thickened septa I find frequently branching channels in which the tubuli contorti end, as shown in microscopic sections (fig. 2). These channels are spaces in the septal membranes, but they have well-developed epithelia. As the lobules occupy the entire space enclosed by the tunica albuginea and are very evenly distributed, no definite mediastinum testis is present, and the channels in the septa

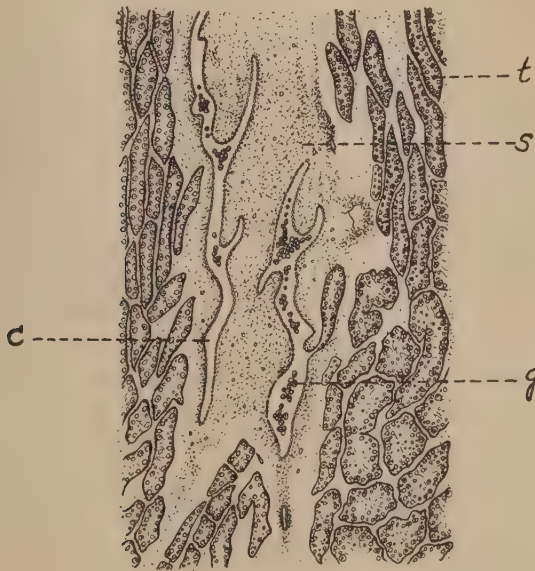


Fig. 2 Part of the cross-section of two adjacent lobules. *c*, channel; *g*, germ cell; *s*, septal membrane; *t*, seminiferous tubule.

represent a part of the rete testis; the distal parts of the tubuli contorti which open into these channels may probably represent the tubuli recti in function. At the dorsocranial region of the reproductive gland is found a relatively large portion of the septal membrane, attached to the internal surface of the tunica albuginea. The channels in this portion of the membrane are about seven in number and penetrate the tunica albuginea. They represent the last portions of

the rete testis immediately inside the tunica albuginea. This portion of the membrane is much thicker than any other, measuring 10 mm. wide and 1 mm. thick. On piercing the tunica albuginea, the channels pass into a short and flattened duct, measuring 6 mm. long and 4 mm. wide, which immediately branches into three narrower and longer ducts connected with the head of the epididymis. This short duct and its branches represent the vasa efferentia.

EPIDIDYMIS

The head of the epididymis is very complicated, consisting of twelve tubules which are connected with one another in a more or less reticulated arrangement. In the case of the right testis the tubules are broader and more flattened (fig. 1, e), thus making this part of the epididymis asymmetrical with that of the left side. At the lower end of the head the channels are collected into two tubules which finally pass into a single tube, the beginning of the body of the epididymis. The tubule of the body is arranged in a close zigzag. When unraveled, it appears as consisting of many segments, each of which is long, spindle-shaped, and triangular in cross-section at its center. The length of the body of the epididymis, when unraveled, measures 17 cm. The body passes into a narrower portion, the tail, which consists also of segments similarly arranged. On account of the small diameter of the tail and its close coils, this portion forms a thin band covered by the tunica vaginalis, closely attached to the dorsal side of the testis. The tail, unraveled, measures 43 cm. or longer.

VAS DEFERENS

As the testis retains its primitive position, the vas deferens passes directly caudad. It is thicker and more cylindrical in section than the body or tail of the epididymis. Throughout its length it persists in irregular convolutions. The lower ends of the vasa deferentia of the two sides converge in the midline into a single ductus ejaculatorius, and at their meeting-point there is a single and simple vesicula seminalis (fig.

1, *vs.*). The length of the vas deferens when unraveled measures 60 cm.

CONCLUSION

In studying the male generative apparatus of the porpoise, it is interesting to note that the different parts are supplementary to one another. Owing to the large number of lobules in the testis, the septa are more numerous than those found in the usual mammalian testis, so that it may be said that the rete testis is evenly distributed throughout the reproductive gland. Consequently, the absence of the mediastinum testis does not result in any functional defect in the organ. The vasa efferentia are small and not so well developed as in the ordinary mammalian testis, but the complicated epididymis seems to assist in passing the spermatozoa in normal rate and manner. Likewise, the much-convoluted vas deferens seems to supplement the single simple vesicula seminalis in functional activity.

THE NORMAL WEIGHT OF THE PANCREAS IN THE ADULT HUMAN BEING: A BIOMETRIC STUDY¹

JOHN H. SCHAEFER

Fellow in Pathology, The Mayo Foundation, Rochester, Minnesota

SIX FIGURES

During an investigation of certain lesions of the pancreas, a knowledge of the normal weight of the gland of adult human beings was found desirable. A search of the literature indicated a lack of agreement on this subject by anatomists. In fact, it seemed justifiable to conclude that no well-founded idea exists of what really constitutes the normal weight of the pancreas in adult man.

Lewis ('18) stated that the normal weight of the pancreas in the adult man is 60 to 100 grams; Jackson ('23), that the average weight is about 80 grams (extremes 60 to 100 grams); Delafield and Prudden ('22), that it usually weighs from 70 to 108 grams, and Braus ('24) merely stated that the pancreas weighs from 70 to 90 grams. None of these authors discusses any difference in the weight of the gland in the sexes. Testus ('12) discussed the matter more fully, remarking that the average weight of the normal pancreas is 70 grams in the adult male and 66 grams in the female. He also said that the weight is quite variable, and in some cases without demonstrable lesion it may be as low as 30 or 35 grams or as high as 100 or 150 grams. He cited Soemmering and Meckel as reporting a pancreas weighing 180 grams, which he seems to regard as being exceptionally large.

¹From the Mayo Foundation for Medical Education and Research, and the Department of Anatomy, University of Minnesota.

Read by title before the American Association of Anatomists, Cleveland, April 9 to 11, 1925.

The most satisfactory statement regarding the normal weight of the pancreas in the adult is probably that of Poirier and Charpy ('01), who say that the average weight is 80 grams and that, like the liver, spleen, and other viscera, it increases in weight up to the age of forty years, and at fifty years commences to undergo senile atrophy. Its average weight is approximately 70 grams between the ages of twenty and thirty; 80 grams, between thirty and fifty years, and 60 grams after fifty. The gland in the female is smaller, weighing, on the average, 10 grams less than in the male. Poirier and Charpy apparently are the only writers who indicate a possible correlation between the weight of the pancreas and sex or age.

Only two extensive collections of the weights of the pancreas of adults have been found in the literature.² Of these Boyd's ('62) is the most extensive; he reported a summarized study of the weights in 1527 cases. The other large series is that of Clendinning ('38), whose data were obtained at necropsy on persons dying from chronic diseases, presumably at the Marylbone Infirmary, London, and therefore from the poorer classes.

Porter ('89) published a rather extensive series of weights of organs, including the pancreas, obtained at necropsy on victims of the Madras famine of 1877 and 1878, but most of the subjects were children. Conroy ('22) published the weights of the pancreas of twenty patients, approximately half of whom were diabetic. Assman ('88) published the weights of the pancreas of ten adults. It is believed that the foregoing covers the more important series of such weights published to the present time.

²After the completion of this paper, an article by Rössle ('21) was found which contained data on the weights of several hundred pancreas. Owing to the fact that the title of the article gives no clue to its actual contents, it had been overlooked. Rössle's cases, like Boyd's, are so grouped that they are not available for statistical study. His criteria with regard to normality are unsatisfactory and the weight differences in association with age fall within the limits of our established standard deviation.

In the Mayo Clinic series³ the weight of the pancreas was noted in 216 adults during necropsy and is summarized in table 1.

MATERIAL FOR BIOMETRIC STUDY

Boyd has grouped his weights of the pancreas in adults so as to preclude the deduction of any values from them except

TABLE 1
Summary of data on the weight of the pancreas of adult man

MATERIAL	MEAN WEIGHT	STANDARD DEVIATION	PROBABLE ERROR OF MEAN WEIGHT	COEFFICIENT OF VARIABILITY	MAXIMAL WEIGHT	MINIMAL WEIGHT	RANGE	CASES
Males								
	grams	grams	grams	Per cent	grams	grams	grams	
Mayo Clinic Series								
Group 1	90.41	23.14	17.63	28.9	150	42	108	67
Group 2	90.31	22.34	15.08	24.7	150	42	108	79
Group 3	104.96	33.72	22.74	32.1	205	46	159	52
Group 4	96.12	28.35	19.12	29.4	205	42	163	131
Clendinning Series	85.15	22.94	15.47	26.9	142	42	100	60
Boyd Series.....	98.16				199	28	171	
Females								
Mayo Clinic Series								
Group 1	85.16	22.42	15.12	26.3	135	38	97	48
Group 2	84.88	22.17	14.95	26.1	135	38	97	54
Group 3	84.56	31.19	21.04	36.8	190	39	151	25
Group 4	84.78	25.39	17.13	29.9	190	38	152	79
Clendinning Series	71.36	11.72	7.91	16.4	117	27	90	50
Boyd Series.....	82.60				170	35	135	

mean, maximal, and minimal weights which, considered alone, are inconclusive. It is understood that the original necropsy protocols from which his data were compiled were lost in the fire which destroyed the Marylbone Infirmary in the latter half of the last century.

Clendinning's series, while suitable for biometric study, is from the poorer classes of London of nearly one hundred

³A copy of the detailed records of the Mayo Clinic series has been placed on file in The Wistar Institute of Anatomy and Biology. These are accompanied with such other data as are considered relevant.

years ago when such patients were, to say the least, inadequately cared for. They died from chronic diseases, were admittedly emaciated, and all weights of organs were low. The obvious subnormality of these weights renders them invalid for establishing normal weights of the pancreas in adults.

The series of weights of the pancreas in adults given by Conroy, Porter, and Assman are too small, individually, for quantitative study, and it is poor practice to group biometric data from such widely different sources. Conroy's series is unsuitable by reason of the large percentage of diabetic subjects included, and Porter's series, because of the obvious emaciation of the subjects, the small number of adults, and possible racial factors.

The Mayo Clinic series is personally collected material from routine necropsy service, and practically all classes of persons are represented. This series may, therefore, be accepted as representative of the general American hospital population. With few exceptions, necropsy was performed soon after death; the exceptions were in subjects who had been embalmed for periods up to forty-eight hours. The embalming, however, probably exerted no appreciable influence on the weight of the pancreas. It is believed that this series is the largest single series of weights of the pancreas in the adult extant which is suitable for a biometric study of the normal weight of the pancreas in adult man.

In obtaining these weights each pancreas was carefully dissected free from all extraneous adipose tissue, large vessels, and so forth. It was weighed in a dry scale pan on an accurate, previously adjusted, torsion balance, and then carefully examined for possible abnormalities.

For reasons stated, the Mayo Clinic series was depended on for the establishment of the mean weight, standard deviation, probable error of the mean weight, and the coefficient of variability of the normal pancreas in the adult male and female. For purposes of comparison, the results obtainable from the data of Boyd and Clendinning are also shown (table 1).

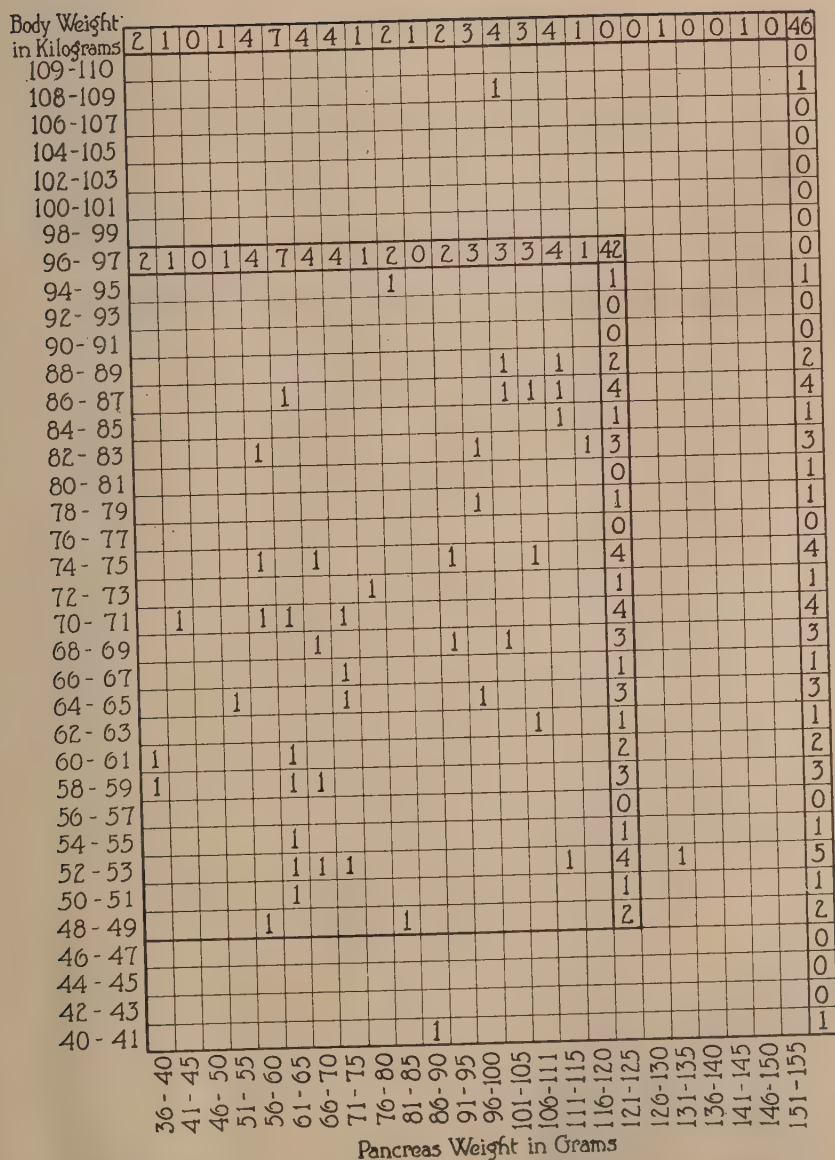


Fig. 1 Distribution of weight of pancreas with respect to normal body weight.
(Adult females, Mayo Clinic series, forty-six cases.)

probable error and the coefficient of variability are the best indexes of the reliability of a series of observations, it is concluded that the values derived from group 2 represent more accurately the true normal weight of the pancreas in the adult than do those derived from group 1. It may be concluded, therefore, that minor abnormalities of form or texture do not, per se, render a given pancreas unsuitable for inclusion

Age in Years	2	4	7	17	19	13	14	4	3	3	4	0	1	91
81-85						1								1
76-80														0
71-75			1		1	1	1		1		1			6
66-70			1	2		2	3							8
61-65				3	1	1			1				1	7
56-60			1	2	3	2	2	1						12
51-55			1		5	3	2			2				13
46-50			1	2	2					1				6
41-45	1		1	3	2	1	1	1	1					11
36-40		1		2	1	1	4							11
31-35	1		1	1	1	1	1	1						7
26-30				1	2									4
21-25		2		1	1			1						5
	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	
	Pancreas Weight in Grams													

Fig. 3 Distribution of weight of pancreas with respect to age. (Adult males, Mayo Clinic series, ninety-one cases.)

in a series of normal weights. The normal weight of the pancreas in the adult in the Mayo Clinic series (group 2) was: male, 90.31 ± 15.08 grams; female, 84.88 ± 14.95 grams.

It is to be expected that those pancreas with adiposity and passive congestion (group 3) will show a greater standard deviation, probable error of mean, and coefficient of variability than the normal. This was noted in both sexes. As

expected, it was also found that in group 3 the mean weight, in the male, was considerably higher than the normal mean weight. In the female, however, the mean weight was actually lower than in any other group of the same series and sex. No explanation of this was found.

Because of the source of Clendinning's series, a much lower mean weight for the pancreas was found in both sexes than in the Mayo Clinic series. The probable error and coefficient

Age in Years	2	1	4	11	5	3	5	7	5	0	1	1	45
71-75				1	1		1						3
66-70				1									1
61-65	1		1	3				1					6
56-60				3	1	1		1	1				7
51-55			1		2	1	2		1				7
46-50		1					1	3	2				7
41-45				1	1	1		1	1				5
36-40	1		2	2			1				1		7
31-35													0
26-30								1				1	2
	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	
Pancreas Weight in Grams													

Fig. 4 Distribution of weight of pancreas with respect to age. (Adult females, Mayo Clinic series, forty-five cases.)

of variability in the weights of the pancreas in the females of Clendinning's series were much lower than in the normal females of the Mayo Clinic series, but the reverse was true in the males. The smaller probable error and coefficient of variability in the weights of the pancreas in the females of Clendinning's series can probably be explained on the basis of emaciation producing a more nearly fat-free pancreas which more closely represents the true glandular organ. I can offer no explanation for the findings in the male.

A peculiar difference in the mean weights of the pancreas in the male and the female is found in each of these three series. In the Mayo Clinic series the mean weights of the pancreas in the adult male was only 5.43 grams greater than that in the female; in Clendinning's series the mean weight in the male was 13.79 grams more than in the female, and in Boyd's series the mean weight in the male (all cases) was 15.66 grams more than in the female. It is suggested that this difference indicates that the pancreas is relatively heavier in the male than in the female in English persons than in Americans. One would be inclined to call this a 'racial difference' if it were not for the cosmopolitan nature of the American population. The final interpretation of this point should be withheld until a series of weights in the English comparable to the Mayo Clinic series has been studied.

TABLE 2
Correlation of normal pancreas weight and body weight

FEMALE		MALE	
i-A. $r = 0.364180$	$e_r = 0.086260$ $n = 46$	ii A. $r = 0.347091$	$e_r = 0.062188$ $n = 91$
i-B. $r = 0.462268$	$e_r = 0.081837$ $n = 42$	ii-B. $r = 0.381283$	$e_r = 0.066122$ $n = 76$

In order to determine the influences, if any, of normal body weight, age, and stature on the weight of the pancreas, correlations have been calculated for each of these factors against the weight of the pancreas for each sex. In preparing such correlations it is desirable to use the identical individuals in each series, and as complete information is not available in all cases, it is obviously necessary to consider only those in which complete data are available. This necessitates the use of smaller groups for correlation than for the establishment of mean weights.

As the adipose pancreas is chiefly found in adipose subjects, it was considered permissible to include every pancreas which showed no gross lesion, whether it was adipose or not.

Figure 1, which illustrates the correlation between the weight of the pancreas and normal body weight of the adult

female, is divided into two parts, A and B. A includes the forty-six individuals considered. B excludes the scattered, and probable abnormal, individuals. Figure 2, which illustrates the same correlation in the male, represents a similar elimination of scattered individuals. The correlations between normal body weight and pancreas weight are shown in table 2. It is seen that elimination of the scattered individ-

Stature in Centimeters	2	1	0	1	4	7	4	4	1	2	1	2	3	4	3	4	1	0	0	1	0	0	1	46
176-177															1									1
174-175																1								1
172-173								1	1															2
170-171																1								1
168-169	1					2	1	1																5
166-167					1	1								1		1								4
164-165						1	1			1		1	1	2										7
162-163					1		1						1	1										4
160-161		1			1	2							1											5
158-159								1											1					2
156-157										1							1						1	3
154-155	1			1								1												3
152-153					1		1				1				2									5
150-151																1								1
148-149																								
146-147						1																		1
144-145																								
142-143																								
140-141																								
138-139																								
136-137																								
134-135																								
132-133																								
130-131																								
128-129																								
126-127																								
124-125								1																1
36-40																								
41-45																								
46-50																								
51-55																								
56-60																								
61-65																								
66-70																								
71-75																								
76-80																								
81-85																								
86-90																								
91-95																								
96-100																								
101-105																								
106-110																								
111-115																								
116-120																								
121-125																								
126-130																								
131-135																								
136-140																								
141-145																								
146-150																								

Fig. 5 Distribution of weight of pancreas with respect to stature. (Adult females, Mayo Clinic series, forty-six cases.)

uals results in a higher correlation ratio between the weight of the pancreas and normal body weight in both sexes, although the ratio remains of the same order of magnitude.⁴

Figures 3 and 4 show the correlation between weight of the pancreas in adults and age of the males and females, respectively, of the Mayo Clinic series.

Female, $r = -0.392799$ $e_r = 0.093240$

Male, $r = +0.122649$ $e_r = 0.069642$

It will be noted that there is a reasonably strong negative correlation between the normal weight of the pancreas of the

⁴ It may be pointed out that *the probable error varies inversely as the square root of the number of observations*. From this it follows that, in a given series of observations, the omission of a number of cases will tend to increase the probable error unless the omitted observations are, in themselves, abnormal sources of error. With this in mind, it is at once noticed that the scattered individuals omitted from figure 1-A to form figure 1-B must be, per se, abnormal sources of error, inasmuch as their omission materially lowers the probable error in spite of the resulting reduction in the number of observations. This justifies omission of the scattered individuals.

The evidence in figure 2 is not so obvious. It is seen that the probable error in table 2, ii-B, is slightly greater than in table 2, ii-A, and one is likely to attribute this to the smaller number of observations. Critical analysis, however, shows that the probable error in table 2, ii-B, while numerically greater than that in table 2, ii-A, is actually smaller than that which would be brought about by a simple decrease in the number of observations.

The probable error of the correlation in table 2, ii-B, may be evaluated as follows:

There are ninety-one observations in table 2, ii-A, and seventy-six in table 2, ii-B. The probable error in table 2, ii-A, is 0.062188, and we shall let X equal the value of the probable error in table 2, ii-B. If this probable error were solely dependent on the smaller number of observations in B than in A, applying the inverse-square law of probable error and putting these data in the form of the equation:

$$\frac{91}{76} = \frac{X}{0.062188}$$

Solving, $X = 0.068045$

Therefore, it is seen that if the probable error in table 2, ii-B, were solely dependent on the smaller number of observations, the probable error would be 0.068045. It is, in fact, however, only 0.066122, and from this it is seen that the probable error in table 2, ii-B, while numerically greater than in table 2, ii-A, is relatively less. The individuals omitted to make up figure 2-B were in themselves abnormal sources of error, and the values obtained from figure 2-B are, therefore, more accurate than those obtained from figure 2-A.

It is therefore established that, for the Mayo Clinic series, there exists a strong positive correlation between the normal weight of the pancreas in the adult and the body weight in both sexes, but that it is higher in the female.

adult and age in the female, but that there is a small positive correlation in the male, with a probable error more than half as great as the coefficient of correlation. Since, in general, it may be stated that any coefficient of correlation should be regarded as doubtful if the probable error is not less than 0.25 the magnitude of the coefficient of correlation, the correlation in the male may be considered insignificant.

Figures 5 and 6 show a test of the correlation between the normal weight of the pancreas in the adult and stature in females and males, respectively. The results are:

$$\text{Female, } r = 0.032409 \quad e_r = 0.099345$$

$$\text{Male, } r = 0.115294 \quad e_r = 0.069776$$

From this it is seen that there is no significant correlation between these factors in the female and that the correlation in the male is so feeble that it is quite negligible.

SUMMARY

A study of the literature shows the absence of an accurate knowledge of the normal weight of the pancreas in man and the lack of any suitable data for the establishment of such normal values. The weights of the pancreas in a series of 216 personally collected cases (with extensive data on each case) are presented and analyzed statistically. The mean weights of the normal pancreas, as established by this study, are:

$$\text{Female, } 84.88 \pm 14.95 \text{ grams}$$

$$\text{Male, } 90.31 \pm 15.08 \text{ grams}$$

A possible racial difference between the weights in the male and female in English and American populations is indicated. A positive correlation is established between the normal weight of the pancreas in the adult and the normal body weight in both the male and female, the correlation being higher in the female than in the male. A fairly high negative correlation is established between normal weights for the pancreas and age in the female, but in the male this correlation is so extremely low and the probable error so high that a correlation cannot be said to exist. No correlation is

I wish to express my appreciation for the advice of Dr. J. Arthur Harris on the mathematics, and Dr. R. E. Scammon on the arrangement of this paper.

BIBLIOGRAPHY

- ASSMAN, E. 1888 Zur Kenntniss des Pankreas. Virchow's Arch., Bd. 111, S. 269-280.
- BOYD, ROBERT 1861 Tables of the weights of the human body and internal organs in the sane and insane of both sexes at various ages, arranged from 2614 postmortem examinations. Phil. Tr. Roy. Soc. London, vol. 41, part 1, pp. 24-262.
- BRAUS, HERMANN 1924 Anatomie des Menschen, Bd. 2. Berlin: J. Springer.
- CLENDINNING, JOHN 1838 Facts and inferences relative to the condition of the vital organs and viscera in general, as to their nutrition in certain chronic diseases. Med. Chirg. Trans. London, vol. 21, pp. 33-68.
- CONROY, M. J. 1922 Quantitative and qualitative changes in the islands of Langerhans in diabetes mellitus. Jour. Metabol. Research, vol. 2, pp. 367-384.
- DELAFIELD, FRANCIS, AND PRUDDEN, T. M. 1922 A textbook of pathology, 12th ed. New York: W. Wood & Co.
- JACKSON, C. M. 1923 Morris' human anatomy, 7th ed. Philadelphia: P. Blakiston's Son & Co.
- LEWIS, W. H. 1918 Gray's anatomy, 20th ed. New York: Lea & Febiger.
- POIRIER, P., ET CHARPY, A. 1902 Traité l'anatomie humaine, T. 2, 2e éd. Paris: Masson et Cie.
- PORTER, ALEXANDER 1889 The diseases of the Madras famine of 1877-1878. Madras: Government Press.
- RÖSSLE, R. 1921 Beiträge zur Kenntnis der gesunden und der kranken Bauchspeicheldrüse. Beitr. z. path. Anat. u. z. allg. Path., Bd. 69, S. 163-184.
- TESTUT, L. 1911-1912 Traité d'anatomie humaine, anatomie descriptive, histologie, développement, T. 4, 6e éd. Paris: O. Doin.

THE LATE EMBRYONIC DEVELOPMENT OF THE THYROID GLAND OF THE ALBINO RAT

HARRY A. KULL

The Wistar Institute of Anatomy and Biology

ONE PLATE (FOUR FIGURES)

It is a matter of interest to determine the sequence of phases in the development of the thyroid gland during its late embryonic period. These phases are the formation of follicles, the appearance of colloid, and, in general, the beginning of secretion. The reports found in literature do not give a uniform picture with regard to these problems.

According to Moody ('10), the colloid appears before the formation of the follicles and, according to many others, the colloid does not appear until the follicles are formed. It is of importance to determine the time of the incidence of these changes in embryonic development, because it seems to be well established for many animals and for man that there is a secretion during this period, but there are apparently differences in the time of its exhibition. It therefore seemed of interest to investigate this problem in the albino rat.

TECHNIC

For this study timed embryos of rats from the experimental colony of The Wistar Institute were used; the possibility of having such material is obviously a great advantage in a study of this nature. The fresh material was usually fixed in Regaud's solution (80 cc. of a 3.5 per cent solution of potassium bichromate and 20 cc. of concentrated formol), which penetrates easily so that smaller embryos may be fixed in toto after making incisions in the neck to expose the thy-

roid gland. In older embryos the larynx with the thyroid gland was taken out, and then it was possible to use a solution containing osmic acid according to Champy ('11-'12). For embedding I used paraffin and for staining mostly Heidenhain's iron hematoxylin. This gives results after fixation with osmic mixtures and stains colloid gray or black. It seems to me that young freshly formed colloid stains black and older colloid more gray; so we find in the same section of an embryo in the larger follicles gray-stained colloid and in newly formed follicles a small quantity of black colloid. This does not necessarily hold in the thyroid of an adult animal.

RESULTS

The striking thing that comes first to notice is the late development of the thyroid gland in the albino rat as compared with other species. According to Kingsbury ('15), the first follicular cavities appear in human embryos of 32 mm., while colloid is not seen until 40 mm. This is equivalent to an age of about two months. Norris ('16) shows a microphotograph from a human fetus of 86 mm. wherein are numerous follicles; this corresponds to an age of nearly three months. Moody ('10) finds in the pig the first follicles in embryos of 70 mm. in length and sees colloid much earlier in embryos of 45 mm. One of his drawings shows well-developed follicles filled with colloid in an embryo of 100 mm. Many authors speak of the presence of colloid in the thyroid gland of tadpoles well before metamorphosis and state that during this process the amount of colloid is much diminished. There are many other examples of the presence of colloid in the follicles in embryos at early stages.

In embryos of the albino rat conditions are different, for I could find neither colloid nor follicles before the nineteenth or twentieth day; that is to say, very shortly before birth, which occurs on the twenty-second or twenty-third day. The cells from which the thyroid gland is developing form in the earlier stages a cluster with a small quantity of connective

tissue. At seventeen or eighteen days these clusters begin to form cords of cells, but these cords are solid. In figure 1 we see the peripheral part of the thyroid gland of an embryo eighteen days old. Here the connective tissue has already separated the cells into groups, and it seems that follicle formation is beginning. This is just the time when cords of cells are formed, and the smaller round conglomerations of cells seen in the figure that are like follicles are in reality cross-sections of a solid cord of cells. Here there is no lumen, but cells are in the center as well as at the periphery. In the following two sections of the series these three groups become united and we find there just a cord of cells as in figure 2. This is the next section after figure 1, and here we can see that the three cell groups stand closer together and show no lumen, but are about four cells in thickness. Then we can see how the large group of cells in figure 1 becomes divided by connective tissue into two cords and each cord is about four or five cells thick. The comparison of both microphotographs shows this and these pictures also show that here in this embryo of eighteen days are neither follicles nor colloid.

Figure 3 shows the peripheral part of a thyroid of a twenty-one-day-old embryo. This is only one day before birth, and yet we see that the follicles are not much developed and do not always contain colloid. The largest follicle in the lower left-hand corner contains colloid which is colored gray. The follicles in the upper left-hand corner contain a very small amount of colloid and the follicle toward the middle is nearly empty. In the same section are other completely empty follicles. In the middle of this section and in the left side of the photograph there are groups of cells that are not quite developed into follicles. In the lower right-hand corner we can see, however, a young follicle, where in the central part is some colloid stained quite black, having an angular shape, and filling the middle part between the tops of the cells. The red blood corpuscles are also stained black, but it is easy to distinguish them and to see that the colloid lies in the middle of a group of cells that are in only one layer.

A significant phase of development is also shown at this stage because it is seen from this figure that the development of the follicles is more advanced in the peripheral parts of the growing gland, while in the central parts we see just the beginning of colloid, filling the space between the tops of the cells and so making follicles.

The real and final development of the follicles filled with colloid occurs a few hours before birth. In the gland of an embryo of twenty-two days we have the same structure as in the gland of a newborn rat. Figure 4 shows such a gland from an embryo of this age, and here we have well-developed follicles and much colloid in them. This is still a growing gland, and therefore we can often find dividing cells, as, for instance, in the larger follicle in the right-hand corner that has the shape of an 8. At the bottom of this 8 we see two daughter cells in the telophase. In this section numerous mitoses show that the cells are rapidly dividing.

If we compare figures 4, 3, and 2, we see that they are all very different, and it seems nearly unbelievable that they are from embryos of twenty-two, twenty-one, and eighteen days. However, it is a fact that a fully developed thyroid gland showing follicles and colloid, such as is found at early stages in human embryos and in embryos of many animals, is to be found in the albino rat embryo only a few hours before birth. It is a fact that colloid is not found until the nineteenth day and that the development of colloid and follicles occurs nearly at the same time. So we see that the rapid growth or development of the thyroid gland begins after the eighteenth day, and that earlier than this growth is merely an increase in the number of cells, and not an organic differentiation.

However, the development of the thyroid gland of man and many animals shows that the secretion of this gland is necessary for the growing embryo, and the question arises as to how matters are in the albino rat embryo.

We must think of the possibility that the gland may deliver some secretion directly into the blood capillaries without filling the follicles. This occurs in the thyroid gland of the

full-grown organisms, where, according to Bensley ('16), "the secretion of colloid into the gland lumen is an accessory and not the primary function of the epithelial cells." This is confirmed by Cowdry ('22) and other authors, so that the colloid in the follicles can be regarded as an excess of secretion or a stock to be used at a time when the organism demands a greater amount of secretion. To admit that the thyroid gland in the albino rat embryo may give some secretion directly into the blood would solve many questions that are raised by the late development of this gland, but here we make suppositions and cannot prove them by facts. It may seem that the undifferentiated nature of the cells in the earlier stages of the thyroid gland in embryos before the seventeenth day speaks against such an hypothesis, but Bensley called attention to the fact that the cells in the parathyroid glands show no signs of a visible secretion, while there is no doubt of their activity.

To determine if the cells in the thyroid gland of the albino rat are secreting would be perhaps possible by a study of their mitochondria. The presence only of mitochondria would prove nothing, however, for every cell of the embryo carries them. If we could find manifest changes in the nature of the mitochondria, that would give us perhaps some means of deciding this interesting question, but I at least have failed in this regard. The polarity of the apparatus reticulare of Golgi shows, according to Cowdry ('22) and some others, the pole of the cell where the secretion is emptied, but this is not such a sure sign, for I ('25) found that the apparatus can be at the same time at both poles of the cell in the chromaffin cells of the intestinal epithelium.

At all events, the fact of the late and sudden development of the thyroid gland of the albino rat shortly before birth opens up many new questions demanding further research.

SUMMARY

The development of the thyroid gland to the stage of function, as detected by histological methods, occurs during the last three or four days of embryonic life. The order of events is as follows:

At eighteen days, cord formation by connective-tissue separation.

At twenty to twenty-one days, follicles appear in the periphery which contain a little colloid, while the central part of the gland merely shows a suggestion of follicle formation.

Between twenty-one and twenty-two days, however, an almost explosive unfolding occurs, so that the gland of the embryo of twenty-two days, the day before birth, is completely folliculated.

I wish to take this occasion to express my appreciation and thanks to The Wistar Institute for the opportunity to carry on this study.

BIBLIOGRAPHY

- BENSLEY, R. R. 1916 The normal mode of secretion in the thyroid gland. *Am. Jour. Anat.*, vol. 19.
- CHAMPY, CH. 1911-1912 Recherches sur l'absorption intestinale et le rôle des mitochondries dans l'absorption et la secretion. *Arch. d'Anatomie Microscopique*, T. 13.
- COWDEY, E. V. 1922 The reticular material as an indicator of physiologic reversal in secretory polarity in the thyroid cells of the guinea-pig. *Am. Jour. Anat.*, vol. 30.
- KINGSBURY, B. F. 1915 The development of the human pharynx. *Am. Jour. Anat.*, vol. 18.
- KULL, H. A. 1925 Die chromaffinen Zellen des Verdauungstractus. *Zeitschrift für mikr.-anat. Forschung*, Bd. 2.
- MOODY, R. O. 1910 Some features of the histogenesis of the thyroid gland in the pig. *Anat. Rec.*, vol. 4.
- NORRIS, E. H. 1916 The morphogenesis of the follicles in the human thyroid gland. *Am. Jour. Anat.*, vol. 20.

PLATE

PLATE 1

EXPLANATION OF FIGURES

1 The thyroid gland of an eighteen-day-old albino rat embryo, showing large cluster of three groups of cells and several cross-sections of cords.

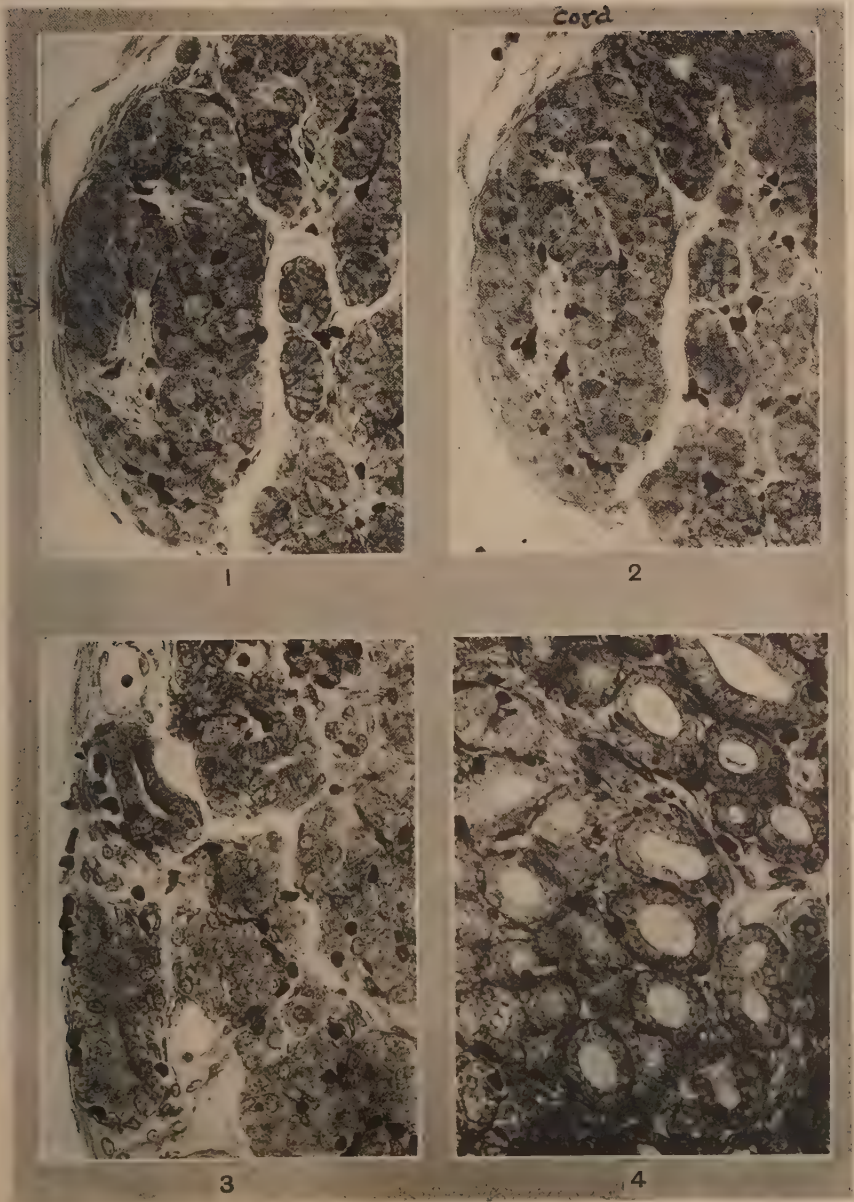
2 The next section of the same gland as in figure 1, showing arrangement of cells into cords in the cluster.

3 The thyroid gland of a twenty-one-day-old albino rat embryo, showing peripheral folliculation.

4 The thyroid gland of a twenty-two-day-old albino rat embryo, showing general folliculation.

Fixation in figures 1 and 2, Regaud; fixation in 3 and 4, Champy. Stained with Heidenhain's iron hematoxylin.

The microphotographs were made with a Zeiss apochromatic objective of 4 mm. with a compensation ocular no. 4 and camera of 40 cm. $\times 400$. Reduced at reproduction to $\times 320$.



A FURTHER NOTE ON THE MOTOR INNERVATION OF THE DIAPHRAGM

KARL SCHLAEPFER

*The Brady Laboratory of Pathology and Bacteriology, Yale University School of
Medicine, New Haven, Connecticut*

SEVEN FIGURES

In an earlier paper the motor innervation of the diaphragm on dogs as determined by previous section of the phrenic nerve in its intrathoracic course was reported. It was shown that four months after operation there is definite atrophy of the paralyzed half of the diaphragm.

The present communication deals with a similar experiment of two years' duration.

EXPERIMENT

On March 28, 1923, the left phrenic nerve of a medium-sized dog was sectioned in its passage over the pericardium. The animal recovered from the operation within twenty-four hours and remained well until the experiment was terminated after two years.

The anatomical findings will be reported only in so far as they pertain to the topic under discussion. Grossly, the whole left diaphragm formed a loose fibrous membrane, contrasting markedly with the muscular right side (figs. 1a and 1b). The central tendon on the left side was still translucent in its most medial portion, but milky white and much more opaque in its lateral portion where it had extended and thickened to replace the muscle. The central tendon on the right side was normal in size and appearance and surrounded by thickened deep red muscle. It is important to note that the line between right and left halves of the diaphragm was not

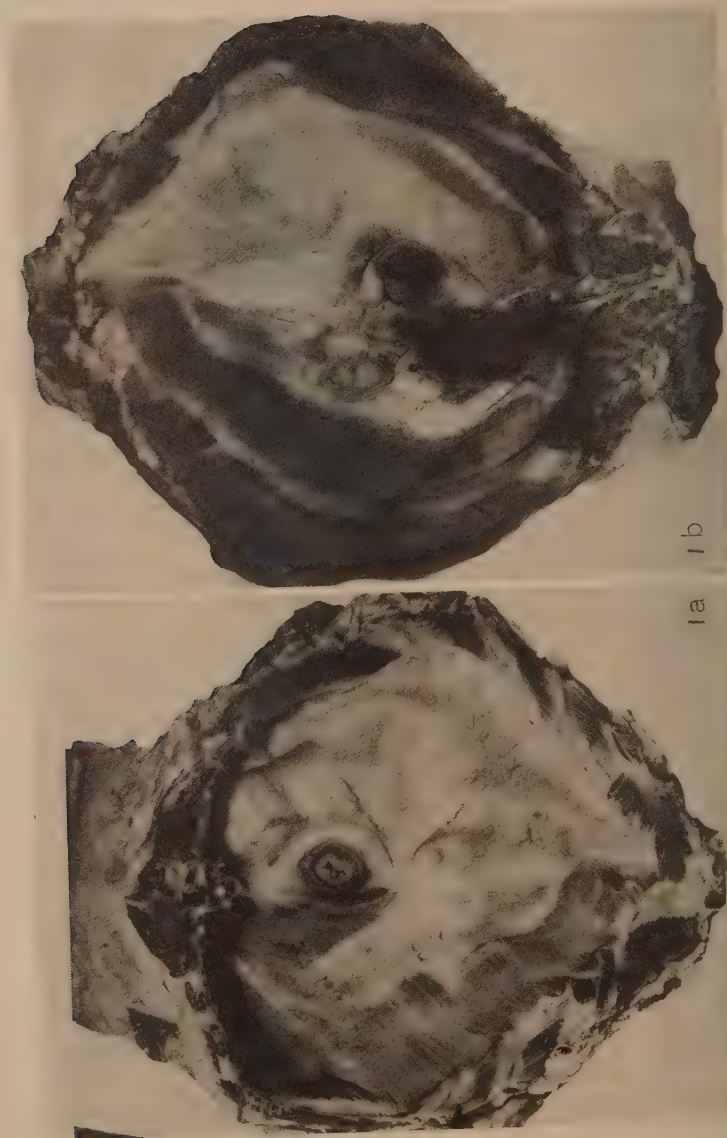


Fig. 1 Photograph of the diaphragm—*a*, viewed from above; *b*, viewed from below—two years after section of the left phrenic nerve in its passage over the pericardium. Note the complete absence of muscle fibers on the paralyzed left side particularly conspicuous in the lumbar portion as compared with the muscular right side.

sharp at the sternal end and that a slender crescent of pale muscle bulged from the muscular right side into the tendinous left side.

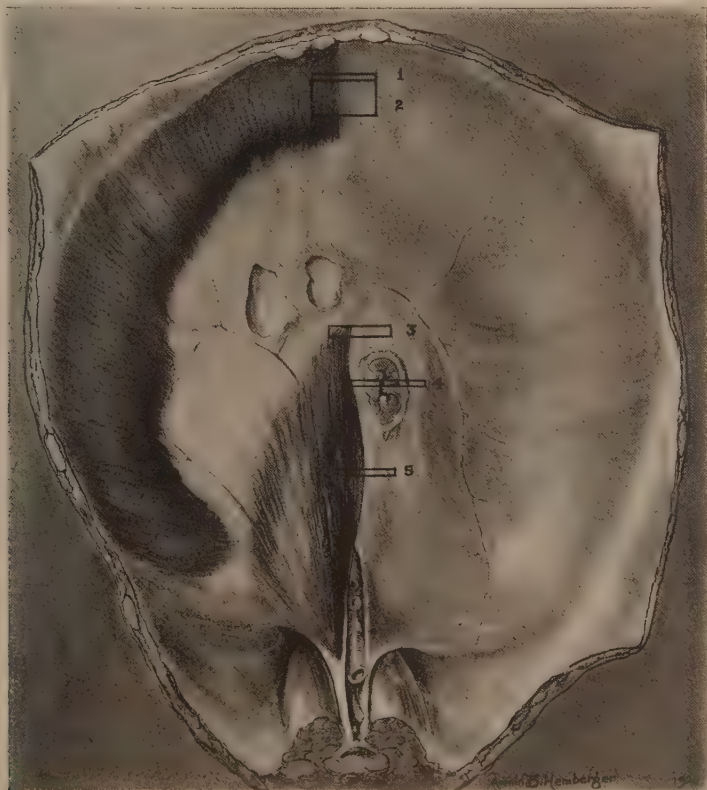


Fig. 2 Drawing of the same diaphragm, viewed from below, with the areas (1 to 5) where blocks were taken for microscopic examination. The numbers correspond with those on the accompanying photomicrographs.

Five blocks were taken to include equal portions of right and left sides from the midline for microscopic examination (fig. 2). The sections are described in order.

1 and 2. In two sections from the sternal portion (figs. 3 and 4), the muscle bundles of the intact side are uniform in

size and separated by loose connective tissue. Beyond the midline ($A-A'$) to the left, the fibers vary in size; the majority are small, few are normal. At a short distance from the midline, atrophy is complete and fibrous tissue has replaced the muscle.

3. Sections through the area anterior to the esophagus (fig. 5) show normal muscle to the right of the midline ($A-A'$). At the midline there is a single bundle of atrophic muscle fibers surrounded by dense fibrous tissue which gives way at its left lateral margin to a fibrous membrane in which no muscle is found.

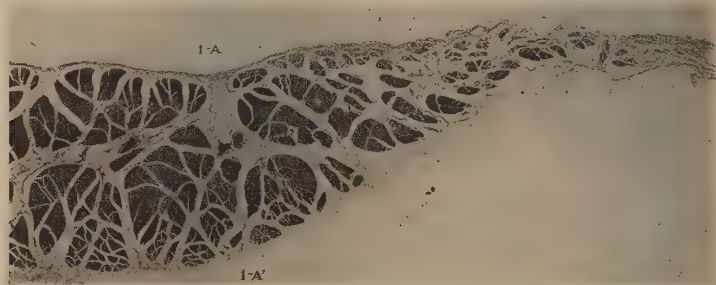


Fig. 3 Photomicrograph of section through the sternal portion with the muscle fibers in cross-section (block 1 in fig. 2). Note the uniform size of the muscle fibers on the intact side; beyond the midline ($A-A'$) to the left, the fibers vary in size. At a short distance from the midline, atrophy is complete.

4. Sections of the wall of the esophagus and adjacent diaphragm (fig. 6) show complete absence of any muscle fibers on the paralyzed side (4, left), but well-preserved muscle fibers on the right (4, right), reaching almost to the muscular wall of the esophagus.

5. Sections taken from the area posterior to the esophagus (fig. 7) show normal muscle fibers on the right, and on the left, only fibrous tissue. At the junction of right and left sides ($A-A'$), the fibrous tissue is much more dense and contains in its center a small but definite island of cartilage.

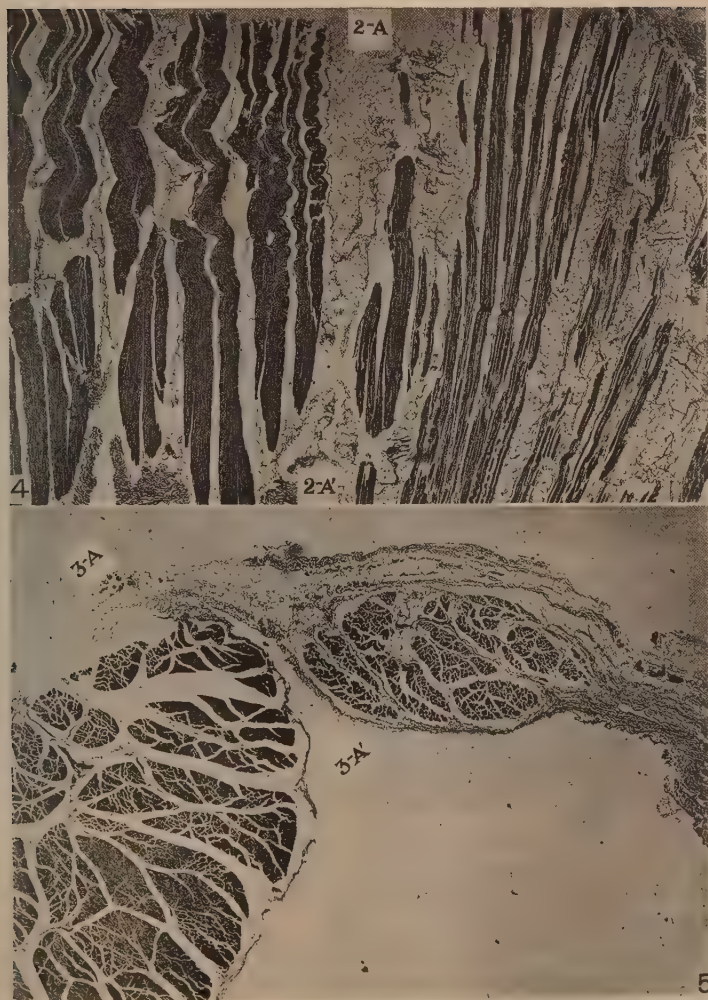


Fig. 4 Photomicrograph of section through the sternal portion with the muscle fibers cut longitudinally (block 2). On the intact side, the muscle fibers are uniform; on the paralyzed left side, the fibers are unequal in size and partly replaced by fibrous tissue.

Fig. 5 Photomicrograph of section through the area anterior to the oesophagus (block 3 in fig. 2) with normal muscle to the right of the midline (A-A'). To the left of the midline, a bundle of atrophic muscle fibers is noted; at its left lateral margin, muscle fibers are absent.

COMMENT

The motor innervation of the diaphragm in mammals is still under discussion. Some maintain that the phrenic is the only motor nerve for the diaphragm (Bertelli, Eisler, Fuchs, v. Goessnitz, Ranström, Russel). Others claim that



Fig. 6 Photomicrograph of section including the wall of the oesophagus and the adjacent part of the diaphragm (block 4 in fig. 2). It shows complete absence of any muscle fibers in the diaphragm on the paralyzed left side (4, left), but well-preserved fibers on the right side (4, right).

the lowest intercostal nerves supply some motor fibers for the portions attached to the lower ribs. (Cavalié, Ellenberger and Baum, Felix, Henle, Schwalbe, Timofejew). Felix assumes that the two vertebral crura which encircle the opening for the aorta and the esophagus receive motor filaments from the celiac plexus of the sympathetic system. Based on the work of Boeke and Aoyagi concerning the interrelationship

of sympathetic fibers and muscle tone, Ken Kuré and Shimbo claim a trophic influence of the sympathetic fibers on the diaphragm. They demonstrate a muscular atrophy and definite change in the cellular metabolism of the muscle following section of the sympathetic nerve.

Distinct early atrophy of the entire paralyzed side of the diaphragm was reported previously as occurring four months



Fig. 7 Photomicrograph of section posterior to the oesophagus (block 5 in fig. 2). Note the normal muscle fibers on the right and fibrous tissue on the left side (*A-A'*: midline). At the junction of right and left sides, the fibrous tissue is dense and contains an island of cartilage in its center.

after section of the phrenic nerve. It is now shown that atrophy becomes complete two years after operation. Only occasional atrophic muscle fibers are encountered just to the left of the midline, and there only in the sternal portion and anterior to the esophagus. Lateral to the esophagus and posterior in the lumbar portion, the diaphragm is completely fibrous in the paralyzed side. The assumption frequently encountered that muscle fibers from the lumbar portion of one

side cross behind the esophagus to the opposite side, therefore, is proved to be incorrect.

LITERATURE CITED

- AOYAGI, T. 1913 Zur Histologie d. Nervus Phrenicus, des Zwerchfelles und d. motorischen Nervenendigungen in demselben. Mitt. d. med. Gesellsch. zu Tokio, Bd. 10, H. 3.
- BOEKE, J. 1913 Die doppelte (motor. und sympathische) efferente Innervation der quergestreiften Muskelfasern. Anatom. Anz., Bd. 44, No. 15-16.
- BOER, DE S. 1913 Die quergestreiften Muskeln erhalten ihre tonische Innervation mittels d. Verbindungsäste d. Sympathicus. Folia Neurologie., Bd. 7, S. 378.
- 1915 Die Bedeutung d. tonischen Innervation f. d. Funktion d. quergestreiften Muskulatur. Ztschr. f. Biol., Bd. 65, S. 1.
- HELLIN, H. 1912 Ueber Zwerchfelllähmung nach einseitiger Phrenicusdurchschneidung. Deutsch. med. Wochschr., No. 31, S. 1491.
- KURÉ, KEN, HIRAMATSU, UND HAITO 1914 Zwerchfelltonus und Nervi splanchnici. Ztsch. f. exp. Path. und Therapie, S. 395.
- KURÉ, KEN, UND SHIMBO 1922 Trophischer Einfluss d. Sympathicus auf das Zwerchfell. Ztsch. f. d. ges. exp. Med., Bd. 26, S. 190.
- KURÉ, KEN, MAÉDE, UND TOYAMA 1922 Untersuchungen über d. Zwerchfelltonus. Ztschr. f. d. ges. exp. Med., Bd. 26, S. 176.
- KURÉ, KEN, HIRAMATSU UND TAKAYI 1922 Experimentelle Untersuchung über d. Entstehung der Relaxatio diaphragmatica. Ztsch. f. d. ges. exp. Med., Bd. 26, S. 164.
- SCHLAEPFER, KARL 1923 The phrenic as the nerve of motor innervation of the diaphragm. Johns Hopk. Hosp. Bull., vol. 34, p. 195. (See further references.)

THE GOLGI APPARATUS—ITS STRUCTURE AND FUNCTIONAL SIGNIFICANCE

ROBERT H. BOWEN

Department of Zoölogy, Columbia University

TWO FIGURES

INTRODUCTION

My purpose in writing this paper has not been merely to repeat the more or less vague suggestions which have already been often assembled under a similar title: for the Golgi apparatus is rapidly acquiring a place as a structural element in protoplasm which demands the general attention of biological workers and bids the cytologist take notice that he must soon consider this material in a more critical light and with a much greater breadth of view than has heretofore been customary. I am led, therefore, to make this somewhat rash attempt to discuss those problems of form and function presented by the Golgi apparatus, for which, broadly speaking, no generally satisfactory viewpoints have as yet been accepted by the disinterested biologist. For these problems, which are in the main a focus of much current controversy and perplexity, I propose to offer some constructive suggestions which may at least throw light upon some general cellular problems from a new angle. Thus, whether or no these suggestions be specifically correct, they may at least lead to the recanvassing of possibilities into which we have not yet sufficiently inquired.

The study of the Golgi apparatus may be dated rather accurately from the identification in 1898 by Golgi of his so-called 'apparato reticolare interno': and this, too, without undue injustice to Platner, whose work on the male germ cells

of pulmonates long preceded Golgi's discovery. It was Golgi's good fortune to demonstrate the internal reticular apparatus by a method which was applicable, even if very uncertainly, to cells of all kinds, and thus his exposition of the subject had an element of universal applicability entirely lacking in the work of Platner and other early workers. Thus the term 'Golgi apparatus' came into general use, and while obviously a misnomer in many kinds of cells, it yet has a significance which admits of no misunderstanding. I will therefore use the old term 'Golgi apparatus' in preference to other competitors, retaining, however, the privilege of varying the second term, as occasion demands, to read Golgi body, Golgi substance or material, etc. It is doubtless true that some better terminology could be devised, but I see no use in making the attempt at least until the physiological significance of the Golgi substance is more fully comprehended.

The history of opinion concerning the Golgi apparatus may be conveniently divided into two periods, of which the earlier one was closed, approximately speaking, with the publication of Duesberg's second review ('14). The achievement of this period toward an understanding of the Golgi apparatus is summed up in Duesberg's own conclusion, "Die Rolle des Golgischen Apparates erscheint mir, wie an Golgi selbst, noch vollstaendig dunkel." This rather discouraging conclusion is traceable, at least in part, to the fact that the dominant factor during this period was Golgi and his school, by whom on every possible occasion the need for reserve in interpretation was emphasized. This attitude led naturally to the repression of illuminating suggestions as to the function of the apparatus, with the result that research was confined principally to certain morphological aspects of the problem. The fact should not, however, be overlooked that during this period a long series of papers was devoted by Holmgren to the elaboration of his familiar Trophospongium Theory—a viewpoint of much interest to the student of the Golgi apparatus, since it is now clear that much of the trophospongium is the Golgi apparatus pure and simple, as Holmgren himself argued.

But it is equally clear that his morphological development of the subject was to that extent unsound, and thus some of his views as to the physiological significance of the Golgi apparatus were overlooked when his fundamental errors of observation were convincingly demonstrated.

Nevertheless, during this first period a large body of evidence bearing on the visible attributes of the Golgi apparatus was accumulated. It was, first, pretty well established that this material had a real existence and was not a mere artifact. It was proved, particularly by the researches of Golgi and his pupils and of v. Bergen, Perroncito, Deineka, and Weigl that the Golgi apparatus is present in all animal cells and is passed on from cell generation to cell generation by division processes which have since been shown to be of very special interest. But as Weigl and his coworkers demonstrated toward the close of this period, the original view of the Golgi apparatus as having a necessarily reticular structure was shown to be quite wrong. These workers demonstrated that in invertebrate cells the Golgi material is frequently not net-like at all, but may be scattered through the cell in the form of absolutely discrete bodies. Thus was broken down the idea that the Golgi apparatus could be identified by its network structure, and there was substituted the modern view of the apparatus as a cellular constituent which may assume almost any shape and distribution, a reticulum being only one expression of its protean appearance. I think it worth while to emphasize this point very strongly and to point out most unmistakably that the morphology of the Golgi apparatus can never be used *per se* as a criterion for identifying it in an unfamiliar guise. Nor, on the other hand, can the fact of an unfamiliar shape ever be urged as a critical argument against the identification of some particular cellular component as the Golgi apparatus.

In this period also it became evident (though the critical proof has been largely the result of more recent studies) that the Golgi apparatus was in no way connected morphologically with the mitochondria, or with the Nissl substance, neuro-

fibres, and other cellular constituents which might be mistaken for it. Significant in this connection is the fact that in his first long review Dreesberg (71) concluded that the Golgi apparatus was merely the result of the impregnation by silver of very different formations, while two years later he had rejected this point of view and had embraced the opinion now generally current. This conclusion has been brought into serious question only by Monro, Combs and coworkers, who have developed a highly convincing conception of the genetic relation of the Golgi apparatus and mitochondria. Their views need not here be given detailed consideration, for recent studies on the formation of animal sperms have conclusively proved that the Golgi apparatus and the mitochondria are absolutely distinct structures—different not only morphologically, but physiologically. Closely related to this question is that of the chemical composition of the Golgi apparatus. And here, curiously enough, it appears that the chemical nature of Golgi apparatus and mitochondria are very similar. As H. Bergen, Sperry, and others, early pointed out, the basis of the Golgi material is lipoidal in character, and later researchers have all tended to bear out this conclusion. More recently, however, it has appeared at least possible that a second constituent of a protein character is also involved—a matter which will be touched on again in another place. This lipoidal basis of the Golgi apparatus has proved to be a very unstable one, and thus it is easily damaged by fixatives, and even after proper preservation, proves very refractory to any but the most complicated sections, and often expensive methods of staining. But what is of most importance in this connection—the behavior of the Golgi material to fixative and staining reagents—is strikingly like that of the mitochondria, and thus it is easily possible to confuse the two—as has in fact often been done. There is, therefore, no specific stain for the Golgi substance, and it cannot be rigorously defined by its behavior toward any known technical processes. This must not be taken too personally by those immersed in the intricacies of cytochemical technique, for

much the same facts can be stated for any cellular constituent. Indeed, the idea of specific stains whereby we may grade our footsteps through the intricate mazes of the cell has now pretty well gone to pieces.

Thus this rather historical period, while failing to offer any arresting explanations of function, did accumulate a great mass of information on various morphological aspects of the Golgi apparatus. The more modern development of the subject dates approximately from an extensive paper by Cajal ('14), who made a serious effort to attack the problem from a functional as well as morphological standpoint. Several valuable papers by Hirschler presently appeared, and at the conclusion of the war the whole problem was approached anew by an attack upon the form and function of the Golgi apparatus in the germ cells. These recent studies have opened most interesting possibilities as to the general functional role of the Golgi material in protoplasm and at the same time have served to clarify and extend the facts of morphological importance which, as already outlined, were the primary contribution of the earlier observers. It is with just these new possibilities, together with some morphological puzzles inherited from the older studies, that I am here interested.

THE STRUCTURE OF THE GOLGI APPARATUS

A question of fundamental interest to the student of protoplasm is that of the genetic permanence of the Golgi material as an indispensable part of the cell system. To this question no categorical answer can at present be given. Nevertheless, the great mass of available evidence indicates that the Golgi substance does not arise *de novo*. In cell division it is very frequently divided by processes of astonishing complexity and regularity, which make certain a physical continuity of substance from one cell to another. Furthermore, it is generally agreed that the Golgi apparatus is capable of growth, and several observers have described the apparent multiplication of Golgi bodies by a process of fission during

the vegetative phase of cell life. As I have pointed out in another place (Bowen, '25 b), however, the division of the Golgi material always partakes of an essentially mass division, and the impression which one gets both in mitosis and in the resting cell is that of a fragmentation process. Thus there is every reason to believe, as Wilson ('25 b) has suggested, that the Golgi apparatus is a substance relatively devoid of specific organization into units of differing significance. It is merely a mass of material which is capable of maintaining itself and of reproducing itself by processes of mass division which are in essence based upon mere fragmentation and have nothing further in common with the highly precise divisions of the nuclear chromatin.

We thus arrive at a very definite conception of the Golgi apparatus as a permanent cell organ, which arises only from preexistent Golgi substance. This is far from the view long ago put forward by v. Bergen ('04), according to whom the Golgi apparatus undergoes a regular cycle of formation and regression so that at some periods it may be lacking entirely from the cell. Such views are now known to have been based upon faulty technical results, which are much better understood than in v. Bergen's time. Nevertheless, in spite of the mass of evidence to the contrary, the view still persists in some quarters that the Golgi apparatus may arise *de novo* as a more or less regular phenomenon. This has been considered possible by Ludford ('25 a) in a recent paper on secretion in the epididymis, and has been described by Brambell ('25) as of constant occurrence in certain oviducal gland cells of the fowl. On the other hand, my own long-continued studies of gland cells, including the epididymis, offer no basis whatever for a description of the *de novo* origin of Golgi substance.

Here, then, is a contradiction which is perhaps at present of no immediate or pressing importance, but which ought constantly to be in the mind of anyone studying the Golgi apparatus. Nevertheless, the weight of evidence is not now in favor of the *de novo* origin of the apparatus, and future

accounts of such a phenomenon ought not to be given as though they were merely restatements of a well-recognized fact. An account of the origin *de novo* of the Golgi apparatus ought rather to be accompanied by every possible evidence of an exhaustive and careful study of the material, rather than a mere inference translated into fact.

Connected with this question of the permanence of the Golgi substance in the cell system is that of its physical consistency. v. Bergen ('04) long ago suggested that its nature was probably 'thickly fluid,' and our present knowledge does not represent much advance beyond this viewpoint. This conception is in a general way supported by the work of Levi ('19), and more particularly of Pensa ('19), who concludes that the Golgi apparatus is a gelified colloid in a denser phase than the more liquid colloidal cytoplasm, which forms the background of the cell. Others, as indicated below, have taken essentially the same attitude. Cowdry ('21), on the other hand, conceives of the Golgi apparatus as a material restricted indeed to certain cytoplasmic areas, but nevertheless of watery consistency—in fact, more fluid than the general ground-substance. Subsequently, however, he ('24) expressed the opinion that in invertebrates where the presence of discrete Golgi bodies is common, the apparatus was probably denser and to that extent different from the highly labile network of vertebrates.

The actual evidence upon which these conclusions are based is confessedly very meager. Cowdry seems to have been largely influenced by the results of microdissection, which he says suggest nothing of the presence in the cell of a rigid network. In general, however, it has not been contended that the Golgi apparatus is a 'rigid' structure, since rigidity is a term scarcely applicable to any protoplasmic element. It has merely been held, I think, that the Golgi apparatus has a sufficient individuality to separate it from the surrounding and more fluid protoplasm. This matter was first attacked experimentally by Cajal ('14) who, after inflicting injury on nervous tissue, examined the cells to see how the Golgi

material had been affected. He concluded from his study that the Golgi apparatus was not liquid, but rather somewhat viscous, of a semisolid consistency, being incapable of diffusing irregularly through the interstices of the neurofibrillar network. Recently (Bowen, '25 b), while studying secretory processes in some of the holocrine glands of the skin, I found that after the break-down of the cell the pieces of Golgi material were easily impregnated in the secretory mass. They retained, for a time at least, the form which they possessed while the cell was still intact. This I take to mean that the Golgi material in these cells at least is sufficiently dense to maintain itself in a foreign environment. Others (Da Fano, '22; Brambell, '25) have made similar observations. Avel ('25) has made the interesting observation on living male germ cells of pulmonates that when the cell is disrupted by crushing, the complex of Golgi rodlets (forming the so-called molluscan *Nebenkern*) does not break up, and the whole apparatus behaves as a relatively firm whole. It would therefore appear that the Golgi apparatus is a really definite material which in some, probably most, cases is set off rather sharply from the cytoplasmic background by its less fluid state.

Coming now to closer quarters with the structural details of the Golgi apparatus, one is rather surprised to find that until very recently little real attention has been given this matter. The older views were for the most part borrowed more or less directly from the canalicular implications of Holmgren's trophospongium; and while the substance of Holmgren's theory was easily disproved, the conception of the Golgi apparatus as a system of canals has persisted even down to the present time. To this viewpoint Golgi was always opposed, and the scattered condition of the apparatus in the egg and in many invertebrate cells certainly argues very strongly against any canalicular construction. In my opinion, the weight of evidence is overwhelmingly opposed to the canalicular theories, and views of this character have contributed not a little to confusing some important problems,

notably the question of the Golgi apparatus in plant cells. Having recently discussed this matter in another place (Bowen, '26 b), it seems useless to go again over the details of what, it must be conceded, has been a fruitless theory.

My own conception of the structure of the Golgi apparatus finds its origins in the studies of Hirschler, particularly his paper of 1918. According to Hirschler, in many kinds of cells, particularly of invertebrates, the Golgi apparatus is not a network of thread-like strands or canals, but a lamellar or plate-like system. The lamellae may form discrete bodies or be loosely integrated into a more concentrated apparatus, as he was able to show with great clearness in the developing embryos of *Lymnaea*. This conception does not seem to fit very well with the classical description of a 'reticular apparatus,' which seems to demand the possibility of a resolution into thread-like structural elements. It was with this long-established conception of a reticulum that I began my observations on gland cells some years ago. At first my results seemed to harmonize sufficiently with the prevailing views, but as my preparations improved technically and the scope of my inquiry widened, it became increasingly difficult and finally impossible longer to accept the thread-work conception of the Golgi apparatus as a generalized basis of explanation. My results indicated that in many glands the Golgi material was not a reticulum of strands, but rather of plates or lamellae. In other words, the substance of the Golgi apparatus was distinctly flattened out, thus forming plate-like surfaces, developed irregularly, and often fenestrated. These surfaces were often interconnected by, or terminated in, thread-like strands. Thus, when the material was properly impregnated by osmic acid, optical sections of the lamellar surfaces assumed thread-like appearances and the impression of a network was a not unusual result. But these outlines were accompanied by a less blackened material, which was shown by close study to represent merely the part of the lamellae seen in surface view. Such appearances are common in salivary glands (Bowen, '25 a) and are developed

with remarkable clearness in the epididymis (Bowen, '26 a). Less perfect impregnations completely obscure these appearances, and it seems probable that sometimes with osmic acid and more frequently after silver nitrate, the apparatus may undergo a general condensation with an accompanying coarse impregnation, which totally obscures its real structure.

This viewpoint was first developed in my critique of the Golgi apparatus in gland cells (Bowen, '26 b), which had already gone to press when I received two preliminary papers by Morelle ('24 and '25), in which similar appearances were described. He looks upon the lamellae, however, as merely the impregnation of an outer zone of a homogeneous mass of 'Golgi substance.' Waiving this difference in interpretation, the actual impregnation pictures which we have obtained are obviously identical.

I have arrived thus at a conception of the Golgi apparatus which cannot be expressed in terms of canals or threads, but only in terms of substance. The Golgi apparatus is a substance which may be scattered through the cell in the form of discrete bodies often plate-like in form, or the substance may be concentrated, leading to a network with strands sometimes in all probability like mere threads, but at other times certainly spreading out to form extensive lamellar surfaces. In other words, the important thing is that the Golgi apparatus is a substance, the exact modeling of which in the cell is purely a matter of secondary interest.

Having thus accounted for the morphological aspects of the material which can be impregnated by osmic acid or silver nitrate, it remains to inquire whether this substance represents the whole of the Golgi apparatus. In cases where scattered Golgi bodies are molded into hollow spheres or hemispheres, and in the circumscribed 'networks' of more classical type, it is natural to inquire whether the spaces thus enclosed contain any substance which might be intimately related to the impregnated material proper. This possibility was first carefully considered by Hirschler ('18), who pointed out that, in the case of hollow spheres, the central contents could not

possibly be the same as the external cytoplasm, and might thus be considered as a part of the Golgi apparatus. To this central substance, which he never succeeded in staining differentially, he gave the name of 'Apparatinhalt.' In the case of half-spheres, he thought it possible that the 'Apparatinhalt' might still be present, though now directly in contact with the cytoplasm proper. These observations were made on the scattered Golgi bodies in the early embryology of *Lymnaea*, and can have no very wide immediate application, simply because Golgi bodies of this form are of restricted occurrence.

With these possibilities as a point of departure, it is of great interest that in the germ cells, both male and female, the Golgi substance typically lies external to a mass of differentiated protoplasm with which it seems to have some very immediate relation. In the male germ cells, more particularly spermatocytes and spermatids, the facts are now very completely known. This material with which the Golgi substance is associated has long been known as the idiosome or centrotheca (figs. 1A and B). It is not an attraction sphere, for so far as known it has no relations whatever with the formation of the achromatic division figure. Hence it cannot be considered as 'archoplasm,' a term continually used by some of the English cytologists in face of the fact that its basic difference from Boveri's archoplasm has been clearly understood for over twenty-five years. Indeed, it was the very absence of any relation between this material and division processes which led Meves ('96) to suggest for it a new name, the idiozom (idiosome or idiozome), which should be indicative of its lack of relation with attraction spheres, etc. In a series of papers on animal sperm formation, I have described the behavior of this idiosome in great detail (especially Bowen, '22), while in the egg cell, the matter has been investigated particularly by Gatenby in his well-known series of papers.

Passing now especially to the somatic cells of vertebrates, it would seem only reasonable to anticipate that a similar

accumulation of idiosomic substance should fill up the space enclosed by the Golgi network. If proof of such a substance were obtainable, it would be a matter of the very greatest theoretical interest, particularly in view of the presumed secretory function of the Golgi apparatus (see beyond). But, unfortunately, such an idiosomic constituent seems to be absolutely lacking, at least in the form here suggested. I have myself spent a long time in an effort to demonstrate such an idiosomic component, but without success—a result which has attended the efforts of most other workers.

There is, however, a slight chance that this substance may be present, but in a form which our technique does not suffice to make visible, and, as noted above, Morelle ('24 and '25) has very recently reopened the whole matter. He suggests that the space enclosed by the Golgi apparatus is as a whole the Golgi substance, the peripheral layer of which is alone blackened by osmic acid to give the characteristic appearances. Another conception of the structure of the Golgi apparatus also suggests possibilities along the line here under discussion. Thus it has been suggested by Harvey ('25), and decidedly claimed by several French observers, headed by Parat and Painlevé ('24, '25, etc.), that the Golgi apparatus is actually composed of a group of vesicles which upon fixation condense the impregnating medium in various ways leading to a false impression of a network, while the bulk of the apparatus proper becomes essentially invisible; in other words, the equivalent in point of position to an idiosomic material. Parat and Painlevé have developed their viewpoint very extensively, basing their conception on a supposed homology with the vacuome in plant cells, as described by Danggaard and Guilliermond. Their observations depend primarily upon the supposed elective staining capacity of neutral red—a capacity disclaimed by some very recent workers (e.g., Karpova, '25), who say, indeed, that the Golgi apparatus will not stain at all with neutral red. A destructive criticism of other features of this theory is relatively easy, but, pending the publication of more detailed results, it seems useless

to pursue the matter. The results of Parat and Painlevé are certainly not now acceptable to the majority of workers on the Golgi apparatus.

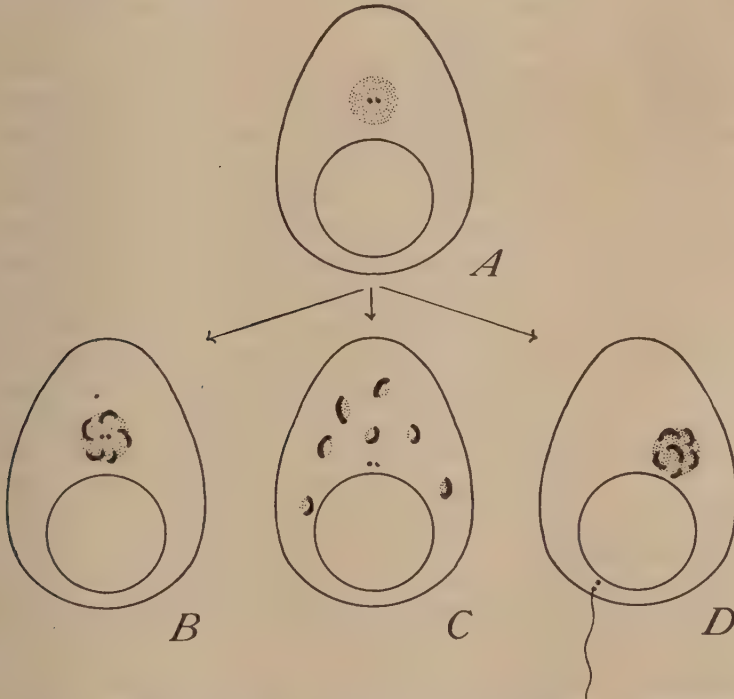


Fig. 1 Diagram to illustrate the relations existing particularly in male germ cells between Golgi apparatus, idiosome and central apparatus. (Idiosomic substance stippled; Golgi apparatus and central bodies in black; nucleus and cell limits in outline.) *A*, idiosome as frequently seen in spermatocytes after acetic-acid fixatives; *B*, Golgi apparatus plus idiosome complex as seen in pulmonate molluscs and many vertebrates after osmic acid without acetic fixatives; *C*, scattered condition of the Golgi complex as seen in insect spermatocytes generally; *D*, spermatid showing complete lack of any relation between Golgi apparatus and central bodies.

It would appear, therefore, that the idiosomic material is characteristic primarily of germ cells and the early cleavage period of the egg, but is absent or invisible, according to the majority opinion, in the established Golgi system of adult

somatic cells. Nevertheless, Morelle's conception is a very interesting one, and the matter should not yet be considered closed. This leaves us with the problem of accounting for the relation so clearly exhibited between Golgi and idiosomic substances in the germ cells.

I suggested some years ago (Bowen, '20) that the Golgi apparatus in germ cells may be in the nature of a duplex system, of which one element, chromophobic in its reaction to stains, merely represented the well-known idiosome, while the other element, a chromophilic one, represented the true Golgi apparatus of authors. Together these components form a unit system which seems to be highly characteristic of spermatocytes and in a lesser degree of oocytes, although recently Voinov ('25) has claimed that this conception of two substances is erroneous, and that the whole complex is rather to be viewed as a single thing—the term idiosome being without any real significance. It has been my experience that these two components are never separated from each other, but some of the English cytologists continually speak as though the relation of the Golgi material to the idiosome (their so-called archoplasm) were a sort of topographical one, which might be readily severed upon occasion. This is a matter of considerable importance, and more critical attention should in future be given to determining the exact nature of the idiosomic substance and of its relations to the Golgi apparatus proper.

If, as seems to me practically certain, these two materials are really inseparably related one to the other, two possibilities concerning this relationship suggest themselves. On one hand, it is possible that the idiosomic material is a specialized differentiation product of the Golgi substance peculiar to the conditions in germ cells. On the other hand, it is possible that the Golgi apparatus is constantly differentiated into two components which are only morphologically distinguishable, with present technique, in the germ cells. Such a differentiation into two materials is already known in the case of mitochondria and chromatin (see also Bowen, '26 b), and is fur-

ther suggested by the general belief that the Golgi apparatus is chemically composed of two different materials, one lipoid, the other protein in character. Between these two possibilities it does not seem possible at present to decide.

This discussion of the idiosome leads naturally to another problem which was formerly much debated, viz., the relation of the Golgi complex to the central apparatus of the cell. The beginnings of this problem date back to the independent discovery of the Golgi apparatus in the epithelium of Descemet's membrane by Ballowitz in 1900. Ballowitz succeeded in demonstrating the apparatus with great clearness and in showing that the central bodies were contained within it. Hence he concluded that he had discovered a 'cell sphere' of unusual development, meaning thereby something homologous with archoplasm or attraction sphere. Thus arose the idea of some real anatomical relation between Golgi network and central apparatus—a relation which Duesberg ('14) has raised practically to the place of a criterion for identifying the Golgi apparatus.

In attempting to clarify this whole matter, it is unfortunately necessary to return once more to the much-confused structure and terminology of the central apparatus. The confusion surrounding this subject is not helped any by the fact that our knowledge of it is based almost entirely on studies made years ago and before the mitochondria or Golgi apparatus were even recognized as constant constituents of the cytoplasm. The nomenclature of the central apparatus had even then reached a stage of such ambiguity that Flemming in 1896 made some suggestions by way of clarification and simplification which I will adopt as still representing the best solution. The central apparatus then consists, when fully developed, of three morphological components: 1) central bodies, 2) a 'heller Hof,' 3) a sphere. The relations of these bodies are shown in figure 2A. The central bodies, often correctly called centrioles (and incorrectly centrosomes) occupy the center of the apparatus. They are frequently enclosed in a small clear area which the Germans speak of

as a 'heller Hof,' but which has never been definitely named. Around this central differentiation is developed, particularly in cleaving eggs and rarely in resting somatic cells, a system of radiating fibers which form the sphere. This latter is roughly the old attraction sphere of Van Beneden. The so-called 'heller Hof' is often indistinctly developed, and in actual preparations the fibrous structure of the sphere is often obliterated. In some somatic cells in the resting condition the sphere seems to be absent, and only the centrioles lying in the 'clear area' can be distinguished (fig. 2C). Now, and this is the crux of the whole matter, a sphere is defined by Flemming as the substance which during division forms a differentiation of any kind around the central bodies at the poles of the spindle. In other words, the sphere is properly a part only of the central apparatus and must by definition take part in the production of the achromatic division figure. It would appear that to this sphere material the term archoplasm, if used at all, should be confined.

Returning now to the relations between Golgi and central apparatus, we find that in a large number of cases the central apparatus occupies a place within the Golgi complex at some stage in the oocyte and spermatocyte, but never in the spermatid (figs. 1B and D). Hence many authors have confused the idiosomic material with a true sphere, and have referred to it incorrectly as archoplasm. This introduces a misconception of no little importance, for it thus comes to appear that the Golgi network has relations to the true sphere which it almost certainly does not possess. That the idiosome is not even remotely related to a sphere was long since known by its failure to participate in the division figure. Its actual relations are indicated, as I have repeatedly pointed out in my papers on sperm formation (particularly Bowen, '22), by its behavior in spermatocytes where the central apparatus is not enclosed by a definite idiosome. In such cases, which have long been known in the insects, I have pointed out that the Golgi apparatus also does not concentrate around the central bodies, but is scattered throughout the cell in the

form of Golgi bodies, each of which is accompanied by a small mass of idiosomic material (fig. 1C). In the spermatids, likewise, the central apparatus has no relation to the idiosome, which may or may not be concentrated (fig. 1D).

Thus it is absolutely certain that the Golgi apparatus, more particularly the idiosome, may have a temporary topographical relation to the central apparatus in germ cells, which, in the present absence of knowledge as to the occurrence or position of the idiosomic substance in other than germ cells, cannot be transferred indiscriminately to somatic cells. It is exactly here that some of the English workers make what seems to me a fundamental mistake. They continually speak of 'archoplasm' in the somatic cells as though it were equivalent to the idiosome of germ cells (which they also call archoplasm), and were similarly enclosed by an associated Golgi network. This is done in spite of the fact that practically no observers have even described any such archoplasm in preparations demonstrating at the same time the Golgi apparatus. The discovery of the constant occurrence of such a mass of material equivalent to the idiosome of germ cells would, as I have already stated, be a matter of extraordinary interest. But in the absence of any such material evidence, it seems to me highly misleading to speak as though such conditions existed and were generally recognized as a part of established zoological fact.

The mistaken conception of the homologous nature of the idiosome in germ cells and the true sphere in somatic cells has doubtless arisen from the fact that in the latter category of cells the Golgi apparatus very generally forms a rough basket in which the central apparatus lies. This relation to the central apparatus has been most clearly shown by Ballo-witz ('00), who demonstrated both central bodies and Golgi net simultaneously. This is in general not possible in somatic cells, and resort must be made to comparisons between the positions of the two structures as revealed each by its appropriate technique. Such studies have been made particularly by Barinetti ('12), and there is no reasonable doubt

that the central bodies are very frequently located within the area included by the Golgi apparatus (fig. 2D). Such cases can be very much extended by comparison of Zimmerman's ('98) figures of the central bodies with those of the Golgi apparatus in similar cells. In other cases, however, of which the epididymis is an outstanding example (Holmgren, '03; Fuchs, '04; Bowen, '26 a, etc.), no such topographical relation seems possible (fig. 2E). This is certainly true in the adult nerve and striated muscle cells of vertebrates and in many cells of invertebrates, in which the disposition of the Golgi substance absolutely precludes any possibility of even a topographical relation.

Generally speaking, in somatic cells the sphere is not developed (fig. 2C), and there is more than a suspicion that many of the 'spheres' described in the older literature are only remnants of a technically mistreated Golgi apparatus. The topographical relation of the usual type of central apparatus to Golgi network is indicated diagrammatically in figures 2D and E. There remain to be considered the cases where an extensive sphere is actually developed, thus producing a real basis for a description of archoplasm, and hence a relation to it of the Golgi apparatus. In the dividing egg where the archoplasmic structures are most extensively developed, the Golgi bodies are scattered through the cytoplasm and have no relation whatever to the 'archoplasm' (sphere material). This, it seems to me, is rather conclusive proof that the Golgi apparatus and the substance of a true sphere have nothing really in common. Thus, in leucocytes where an extensive sphere is apparently developed in the resting stage, coinciding in position with the Golgi apparatus (Verson, '08; Cowdry, '21), my conception of the relations is shown diagrammatically in figure 2B. The Golgi apparatus merely encloses the sphere whose radiating fibers of 'archoplasm' pass outward through the interstices in the network. Here, no more than in the sphere of dividing egg cells, does there appear to be any real organic relation between the two structures.

If, now, we may summarize these rather confusing details, the following conception seems for the present justified. Between central apparatus and Golgi apparatus there is a frequently recurring topographical relationship. This is typi-

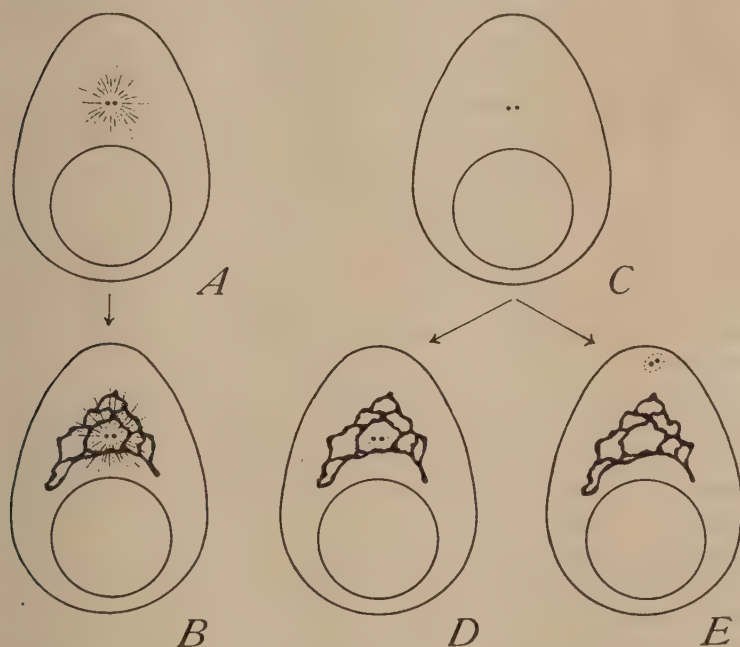


Fig. 2 Diagram to illustrate the probable relations existing in somatic cells between Golgi apparatus and central apparatus. *A*, fully developed central apparatus as demonstrated in leucocytes, etc., by acetic-acid fixatives; *B*, probable topographical relation of Golgi apparatus to the preceding type of central apparatus; *C*, usual appearance of central apparatus in somatic cells after acetic-acid fixatives; *D*, probable relation of Golgi apparatus to the preceding type of central apparatus; *E*, condition in at least some somatic cells, showing complete lack of any relation between Golgi and central apparatus.

cally developed in some epithelial, connective tissue, blood and germ cells, and very probably in embryonic tissues generally. But it is often lacking in the earliest oocytes, in growing spermatocytes and oocytes, and always in spermatids and in the earlier stages of development (probably at

least up to the gastrula condition). It is similarly lacking in nerve cells and striated muscle and occasionally in many other kinds of cells. Hence it may be concluded that the relation between Golgi apparatus and central apparatus is primarily topographical, effected perhaps by the same factors as those which organize cellular polarity in general, and is not of the nature of an anatomical relation as suggested by Barinetti ('12) and Ballowitz ('00 a and b). Nor is this relation of any special use as a means of critical identification of the Golgi material, for those cases which present real difficulties are exactly those in which the central bodies have no distinguishable relations with the Golgi apparatus. Furthermore, the material which in the germ cells has often been confused with the sphere, actually has no relations with the central apparatus, but is probably a part of the Golgi complex to be carefully distinguished from the 'archoplasm' as the idiosome, idiozome, or idiozom. In somatic cells, generally, a sphere (archoplasm) is not usually developed, and hence the ascription to such cells of a relation between Golgi complex and sphere is mistaken. In the few cases, finally, where a sphere, as distinguished from remnants of poorly preserved Golgi substance, is actually developed, it is again probable that the relation to the Golgi apparatus is one of mere topography. Thus Golgi apparatus and sphere (archoplasm) have no real relations to each other, but the possibility that the occurrence of idiosomic substance may find an extension to somatic cells should still be carefully considered, including the possibility that some structures once called spheres may rather have affinities with the idiosome. The possible establishment of such an extension calls, however, for much more critical study than has usually been given the matter heretofore.

THE GOLGI APPARATUS IN PLANT CELLS

All that has thus far been said in this paper applies only to animal cells, and the actual fact of the matter is that the Golgi apparatus has not been identified as yet with anything

approaching certainty in plant cells. We are thus in the position, at least for the moment, of being obliged to admit that plant and animal protoplasm, long described to our elementary students as 'essentially identical,' seem actually to differ in the fundamental fact that the Golgi apparatus is lacking in the plant cell. Such a conclusion seems simply impossible, and it is high time that a more intensive survey of the conditions in plant cells be seriously undertaken. The discussion here offered is largely by way of suggesting a possible solution based on the scanty data now available.

The recent work on the cytoplasm of plant cells has been well summarized by Guilliermond ('24), whose conclusions serve me as a convenient point of departure. According to Guilliermond, the plant cell consists of an undifferentiated cytoplasmic background in which are suspended several categories of elements. One of these is the 'granulations lipoides,' scattered granules of lipoidal affinities which are conspicuous in living cells, do not stain like mitochondria and seem to appear in the cytoplasm directly without relation to any preexisting formed elements. These formations can be dismissed from present consideration by apparently general consent. In addition to these bodies, the cytoplasm contains a more or less complex system of spaces, usually referred to as vacuoles, and recently reexamined and renamed by Dangeard the *vacuome* or *vacuolar apparatus*. This system has been extensively studied by Guilliermond. It is not easily demonstrated after the usual techniques, but it has a very great electivity for neutral red which permits its study in a thorough manner in living cells. It consists, in relatively undifferentiated cells, of a collection of very small vesicles, which later gradually swell up and fuse, forming a complicated network of vacuoles, and eventually by the absorption of water filling large areas of the cell in the well-known manner of the plant vacuoles. Guilliermond ('20, etc.) at first believed that the primordia of this system were mitochondrial in nature, but Pensa ('17) criticised this point of view very destructively, and Guilliermond ('24) has now accepted the

view that the vacuome is something distinct from all the other cytoplasmic differentiations. He repudiates the cell-organ views of De Vries, and believes "that the vacuoles result simply from the swelling up of certain substances not miscible with the cytoplasm, which constitute a permanent secretion of the latter. They would appear to be able, according to circumstances, either to be transmitted from cell to cell or to arise *de novo*."

To cut short a long story, Guilliermond believes that the vacuome is the representative in plant cells of the Golgi apparatus in animals. The point of departure for this view goes back to the suggestions made by Bensley ('10) as to the possible equivalence of plant vacuoles to the 'canalicular apparatus' of animals. This comparison rests, of course, on the assumption that the Golgi apparatus in animals is a system of canals—something which it almost certainly is not. Later workers, Guilliermond and Mangenot ('22), Sanchez ('22), and others, have accepted and extended this hypothesis, the most recent contributions being those of Parat and Painlevé, already mentioned, who seek to establish a vacuome in the animal cell stainable likewise in life by neutral red and equivalent to the so-called Golgi network. Pensa ('17) has not accepted such comparisons, and his remarkable studies on plant protoplasm give considerable weight to his opinion.

Considering the facts more in detail, it appears that the vacuome has only the following points of resemblance to the Golgi apparatus. It may have at one time in its development a net-like arrangement which can be impregnated by silver nitrate after the manner of the Golgi substance—facts admitted by everybody. But, except for this transitory net-like phase, it lacks even a superficial similarity to the usual morphology of the Golgi apparatus. Furthermore, as everyone knows, silver nitrate will impregnate almost anything on occasion, and to its action in an otherwise doubtful case very little significance can be attached. Furthermore, the chemical composition of the vacuome does not agree with that of the

Golgi apparatus, as it often contains phenol derivatives and anthocyaninic pigments. Finally, there is nothing about its relation to the physiology of the cell which suggests the behavior of the animal Golgi apparatus. Personally, I think that present evidence does not establish the homology of the vacuome and the Golgi apparatus; that, indeed, it rather points strongly in the opposite direction. The vacuome itself is not the Golgi substance, and if the vacuome has any representative in the animal cell, we seem scarcely in position at present to discuss it intelligently. However, the possibility that the vacuome may arise in connection with true Golgi material must, of course, be borne in mind.

There remains for consideration in the plant cell what Guilliermond calls the chondriome. This is composed of a large number of scattered bodies which in the meristem cells are usually very small. Close study indicates even here (or in any event in immediately subsequent stages) that the bodies are of two kinds as indicated by their size. One kind is rather granular, the other slightly larger with a tendency toward an elongate shape. The chondriome is thus conceived as of duplex composition, both categories of its units being distinct and self-propagating throughout the history of the plant. The chondriosomes which are differentiated by their smaller size undergo very slight changes, at most only to the extent of becoming somewhat elongated as the cell differentiates. This category never takes any part in photosynthesis and is characterized by its apparent indifference toward all the physiological processes of the cell. The other, somewhat more conspicuous, component of the chondriome undergoes a great development, usually assuming the form of long chondriocents or threads. Thus they are unmistakably distinguished from the other variety of chondriosome, from which they differ also in being more fragile and less easily stained *intra vitam*. Both categories can usually be indistinctly seen in the living cell without staining. This second category of the chondriomal elements is destined to form the various kinds of plant plastids, of which the starch-forming varieties are best known.

In attempting a critique of these very novel results, it must be constantly borne in mind that throughout the range of animal cells there is no evidence of a duplex differentiation of chondriosomes, and this fact in itself would seem to bear heavily against Guilliermond's interpretation. Nevertheless, that there actually are two categories of bodies in the plant cell, of which one is distinctly different from plastids, has been claimed also by Mottier ('18) and is suggested by the work of Meves ('17). The latter found that, in addition to the chondriosomes which were transformed into plastids, there were also many granular bodies present which stained less intensely than the thread-like mitochondria proper. These Meves called metaplasmic granules. Mottier ('18) denied the mitochondrial nature of plastids, contending that they were distinct from the chondriosomes which were actually present in the cell, but took no part whatever in photosynthesis. There is thus very substantial reason for a belief in the occurrence in plant cells of two different, though in many respects similar, classes of formed bodies. One includes the plastids, the other non-plastid-forming bodies. I wish to suggest the possibility that these two components of Guilliermond's chondriome actually represent the chondriosomes and the Golgi bodies of animal protoplasm.¹ At present too little is known of the true nature of these plant elements to permit any categorical statement as to which is which, but it is interesting to note that evidence can be assembled in support of either of the two possible ways of identifying them.

Thus, assuming that the chondriosomes of Meves, i.e., the plastid-forming bodies of Guilliermond, are the homologue

¹ It is only with some hesitation that I have decided to offer these suggestions at this time. I am fully aware of their divergence from the more generally accepted viewpoint. Nevertheless, I think it worth while to draw sharp attention to the insecure foundation of fact upon which some current theories of the structure of plant protoplasm are based. I have this whole matter now under investigation and hope soon to achieve some definite results. Pending the outcome of these and similar researches, it is to be hoped that the views here suggested will be received in the spirit of open-mindedness which for the present it seems essential to adopt.

of the animal Golgi apparatus, a most interesting supporting argument can be easily built up. In the first place, the evidence tends now to indicate that secretion in animal cells is linked to the Golgi apparatus rather than to the mitochondria (see beyond). Hence we might expect that synthetic activity in the plant cell would be related not to mitochondria, but to the Golgi material. Indeed, one of the strongest arguments for the mitochondrial nature of plastids was exactly the supposed relation of mitochondria in animal cells to secretory phenomena. Thus the a priori argument in favor of the derivation of plastids from Golgi substance is at least as powerful as the old reasons advanced in favor of a mitochondrial derivation, and allows us to align the plant cell with the phenomena in animal secretory cells in a most suggestive way.

From the standpoint of mere morphology, no particular argument can be built up. Undoubtedly, the morphology of the plastid primordia had much to do with their identification as mitochondria, but there is no reason why the Golgi apparatus might not have the same shape. It need only be remembered that when the scattered condition of the Golgi apparatus was first described, it produced only incredulity because of its anomalous morphology. But it is now clear that there can be no critical determination of what is, and what is not Golgi substance merely on the basis of the form assumed. As regards the physical and chemical characters of these plastid-forming bodies, they seem at least to admit of the possibility under consideration. The only marked difference, indeed, is the readiness with which they are said to stain by mitochondrial methods. But identical qualities attach to the Golgi apparatus of many male germ cells and a few somatic cells of invertebrates. As regards their reaction to silver nitrate, the beautiful researches of Pensa ('12) indicate that at times they react quite specifically, while the non-plastid-forming mitochondria do not blacken. Nassonov ('18) has shown that these plastid-forming threads blacken like the Golgi material in osmic acid, although he himself interpreted

his findings in accord with the dominant chondriosome theory. Further, he has described an extraordinary division process in which the threads are assembled at the spindle poles even before the mechanism for actual cell division is set up—a result substantiated by the earlier and somewhat obscure findings of Lundegård ('10) on the plastids. Such very striking division phenomena are highly characteristic of dictiokinesis, but have not been found in chondriokinesis, at least in somatic cells. Finally, a paper by Drew ('20) should be noted. By a bizarre technique, Drew succeeded in staining differentially in onion root-tips two categories of bodies. One consists of scattered granules, evidently equivalent to the chondriome of Mottier and the inert type of Guilliermond, and actually identified by Drew as mitochondria. Under slightly modified conditions, another type of body was stained, identified by Drew as the Golgi apparatus. These latter bodies may be thread-like or, in other cells, compact oval or lenticular bodies, quite as described by Guilliermond for the plastid elements. Drew did not compare these bodies with any known structures in plant cells, but his figures suggest that they are plastids or plastid-forming threads. The identification as the Golgi apparatus rests largely on their chemical behavior, more particularly their reaction to post-chroming. In this, the two categories of bodies respond in a manner similar to that commonly met with in the male germ cells of animals. While such a method of identification is admittedly uncritical, it is interesting that Drew's results conform to the possibilities suggested from other sources.

Reasons for identifying the plastid-forming elements of plant cells with the Golgi apparatus may be further multiplied, but enough has been said to indicate the nature and scope of the available evidence. On this hypothesis the non-plastid-forming bodies would be considered as true chondriosomes—an identification already urged by Mottier and supported by their apparent inactivity.

But in spite of this remarkable accumulation of observations which point to the plastid-forming elements as the Golgi

substance of plant cells, it must be admitted that their generally accepted identification as true mitochondria is strongly supported by facts both of morphology and staining capacity. Assuming, therefore, the alternative identification suggested above, i.e., that the plastid-forming bodies are of truly mitochondrial origin, the possibility is still open that the non-plastid-forming granules may represent the Golgi apparatus. Evidence in favor of this view is very scanty, chiefly because these bodies have been very little studied. But their occurrence in the form of sharply circumscribed and scattered bodies at least suggests the disperse type of Golgi apparatus made so familiar by studies on the developing oocyte and on invertebrate tissues.

Which one, if either, of these two possibilities may eventually prove the correct explanation, we cannot now decide, and when all is said and done, the matter can only be settled by an appeal to the plant cell itself. When such an appeal is finally seriously taken, it must be with the distinct understanding that criteria of shape and staining reaction cannot alone suffice to render a conclusive verdict. Only when we find components which behave in a physiologically comparable way can we be reasonably sure of establishing homologies. I have thought for a long time that the best place to attack the problem is in the male spermatozoid-forming line of cells. Here, in the animal, we find the Golgi apparatus involved in a specific process and usually distinguished likewise for its unusual staining capacity. Similar conditions in the plant cell are at least a possibility. The whole matter, finally, is put within reach of a probable solution by the extraordinary conditions in the sperm formation of *Polytrichum* as described by Allen ('17). Here a 'limosphere' gives rise to an 'apical body' in a manner so astonishingly similar, even in some minute details, to the formation of the acrosome in the animal sperm from the Golgi apparatus, that, as Wilson ('25 a) was first to suggest, the identity of the limosphere with the Golgi apparatus can be considered as scarcely less than certain. And this limosphere, it is interesting to note, is not

a product of the 'vacuome,' and hence cannot be compared with the Golgi apparatus-vacuolar apparatus homologies held by Guilliermond. Nor are the comments of Allen ('17) on the supposed occurrence of starch grains, possibly associated with the limosphere in later stages, devoid of interest in connection with the possibility that the starch-forming centers in plant cells may conceivably be the Golgi apparatus.

THE FUNCTION OF THE GOLGI APPARATUS

The problem presented by the Golgi apparatus from a functional point of view is in a much more uncertain state than that of its structure. Nor need this be cause for surprise when we recall the enormous amount of research on another cytoplasmic component—the chondriosomes—which eventuated only in confusion. To the student of the Golgi apparatus, however, this work on the chondriome taught the very valuable lesson of caution in drawing sweeping conclusions from admittedly difficult and equivocal observations. Nevertheless, the constructive suggestions of Meves led to the reexamination of many neglected problems, and if the results have not been entirely satisfying, the outcome can be laid not to the suggestions, but to the extraordinary difficulties of cytological observation. It has seemed to me worth while, therefore, to attempt a tentative synthesis of the available data bearing on the function of the Golgi apparatus, with the primary idea of suggesting possibilities for further research. It must be distinctly understood that most of this section deals with the possible extension of a few known facts to a great mass of data as yet unintelligible from a functional standpoint. This section is indeed one big suggestion, in no sense is it to be taken as a credo.

It will be convenient to consider the problem under the following classification of tissues, which offers certain advantages over the one usually adopted by orthodox histology: 1) germ cells, 2) epithelia, 3) connective tissue, 4) blood, 5) muscle tissue, 6) nervous tissue.

I take as my point of departure the male germ cells because, with respect to the Golgi apparatus, they present a remarkable element of certainty sadly lacking in cytoplasmic conditions generally. I have recently shown in a long series of papers (see particularly Bowen, '22) that the acrosome of the animal sperm arises in association with the Golgi complex of the spermatid; that indeed the acrosomal substance is rigorously defined as that material which is contributed to the sperm by a process of differentiation involving, so far as we can now see, only the Golgi complex. I do not know that any one has made an effort to deny this conclusion, and it is supported by so much collateral evidence accumulated during thirty years of study by many workers, that an error in the facts seems impossible. This case is of very much more interest than appears superficially, for it represents well nigh the only case in animal cells in which a structure arising *de novo* in the cytoplasm has been traced to its indubitable source.

Concerning the details of this familiar phenomenon, it is useless to speak, and I wish only to recall how, in typical cases, the acrosome first appears as a minute vesicle in contact with, or embedded in, the Golgi apparatus plus idiosome complex. This vesicle gradually enlarges until at completion the Golgi complex is cast off and usually lost in its entirety. The point of extraordinary interest is that the Golgi complex is not *per se* made into the acrosome. It merely acts as the material basis of a process in which its own substance is apparently not consumed in any important degree. It is indeed a visible demonstration of the 'process theory' of cellular physiology. I call particular attention to this case because, in the perplexities of cytoplasmic investigation, it affords a comforting point of certainty from which to make further sallies into the mazes of the cell. Therein lies its danger, for we may unwittingly push the case too far; but therein lies also the possibility, as I am now going on to suggest, that it may actually be a prototype of many other cellular processes at present beyond our understanding.

It would be a most engaging coincidence should we find in the egg an activity of the Golgi apparatus comparable to that in the sperm cells. To state the possibility more specifically, that there is a relation between the Golgi apparatus and the formation of yolk—a material which is the primary differentiation product of the cytoplasm of practically all eggs. Unfortunately, on this point there is the most astonishing lack of uniformity in opinion. Some half-dozen or more sources of yolk material, exclusive even of the Golgi apparatus, have been seriously described. These I cannot consider here, but the case for the Golgi apparatus is of immediate interest. The matter has been examined in a considerable variety of forms by nearly a dozen observers with the most remarkable results. Thus Hirschler ('13), Harvey ('25), and Cattaneo ('14) find no evidence that the Golgi apparatus is involved at all in vitellogenesis. Nath ('24 and '25) finds that one kind of yolk material is formed by an apparently direct transformation of the Golgi substance itself. Brambell ('24) finds one type of yolk arising directly from the chondriome, and another type arising either directly from, or under the influence of, the Golgi apparatus. Ludford ('21) describes a development of yolk spheres in association with the Golgi apparatus, essentially comparable to the mode of origin of the acrosome. Hirschler ('16) finds the yolk granules arising directly from mitochondria and being completed by a secondary fusion with Golgi bodies. Gatenby and Woodger ('20), reviewing vitellogenesis, derive the yolk in different animals from the cytoplasmic background, from Golgi apparatus and possibly mitochondria, from mitochondria alone, from mitochondria and possibly Golgi apparatus, and possibly from extruded nucleolar material. In the absence of any possible feature of a generalized character, it is useless to go into details or to catalogue further differences of opinion. It is clear to the most biased reader either that some one must be wrong, or else that there are many different kinds of yolk which even in closely related animals are produced in widely different ways—a view in agreement with

Wilson's ('25 a) recent statement of the dilemma. One is indeed irresistibly reminded of an old quotation, "Die Natur ist immer einfach, nur der Irrthum redet mit tausend Zungen." These words suggest my own point of view. That each species or genus has its own peculiar mode of producing yolk, seems to me to contradict everything else which we know about vital processes; and the uniformity in principle coupled with endless variation of detail in the formation of the acrosome in the male, suggests that vitellogenesis, while undoubtedly a more complicated problem, is nevertheless at bottom a process which is always essentially the same. The differences in details of a very obscure process have completely confused us. The following comments are merely suggestive of a possible way out.

A perusal of the literature on yolk formation, and more particularly on the results of centrifuging eggs, suggests that eggs may in general contain not many, but two, and only two, types of 'yolk.' One of these is of a lipoid nature, easily blackened by osmic acid and forming the familiar oil cap at the centripetal pole of a centrifuged egg. The other type of 'yolk' is usually more abundant, does not usually blacken in osmic acid, and represents what is in itself ordinarily termed 'yolk.' It occupies the heavy pole of a centrifuged egg. These two classes of deposit are particularly well illustrated in the pulmonate molluscs and in *Ascaris*. The other feature worthy of note is the universal (with an equivocal reservation in mammals) breaking up of the Golgi apparatus during the growth period of the egg. On this point all authors are agreed, the Golgi apparatus occurring in the mature egg always (except as noted above) in the form of scattered bodies. In some forms these Golgi bodies are of considerable size as in *Ascaris*, where the yolk bodies are also large; while in other forms the Golgi pieces are minute, and the yolk spheres are correspondingly very numerous and small, as in *Patella*. Now, in skin glands where the cells produce a mass of lipoidal droplets, the production of which has been shown to be associated apparently with the Golgi apparatus,

the apparatus always breaks up into pieces very reminiscent of the picture in developing eggs (Bowen, '25 b, and Ludford, '25 b). There is here at least a suggestion that a similar relation between yolk and Golgi substance may occur during vitellogenesis, as described by Ludford ('21), and also that to some extent there may be a correlation between the sizes of yolk granules and of Golgi pieces, as noted above in two specific examples. It may also be that the Golgi apparatus is involved in the formation of one general type of yolk material, while yolk of a second type (as suggested above) is otherwise derived. In any event the extraordinarily small size of the Golgi bodies will always make the solution of this problem a very difficult one, and if one good case can be established we should not be too skeptical in extending the result to other cases which may well be technically impossible. We have also to reckon with the possibility, beyond morphological analysis, that yolk granules may arise in the cytoplasm through the activity of enzymes secondarily disengaged from their possible place of origin in the Golgi apparatus.

Passing, now, to the second group of tissues, the epithelia, we have first to note the interesting conditions in secretory cells, which are now so well known that it will be unnecessary to go extensively into details. The possibilities in this direction have been explored at various times by several workers, but the first significant contribution was made by Nasonov ('23 and '24 a). By the aid of a much-improved technique he was able to impregnate the Golgi apparatus with great precision and at the same time to demonstrate the secretory granules very clearly. In the course of an extended study of many types of secretory cell I have been able (Bowen, '24 b, '25 a, b, '26 a) to corroborate Nasonov's findings in most of their important details, and Morelle ('24 and '25) and Ludford ('25 b) have arrived at essentially similar conclusions. It is now clear that the Golgi apparatus marks out an area in the cell within which the secretory granules always make their initial appearance. The mitochondria seem to have no direct part in this process, although on this point there

is as yet no final or unanimous opinion. During the secretory cycle of the cell, the Golgi apparatus exhibits a very striking and characteristic increase in size and complexity. The secretory granules seem to be differentiated by the Golgi apparatus, but in this process the substance of the apparatus is not consumed, and in many cells is actually at the peak of its development as the secretory cycle reaches its culmination. These facts have led me to suggest (Bowen, '24 b. and '26 b) that the relation between Golgi apparatus and secretory granules is comparable to that exhibited on a simpler scale by the developing acrosome of the animal sperm. Thus the possible enzymatic nature of the acrosome is suggested, together with a new view of its rôle in fertilization (Bowen, '24 a), and at the same time the mode of origin of secretory granules is accounted for. It would, perhaps, be assuming too much to say that the origin of secretory granules has thus been definitely solved; but I think it beyond gainsaying that an important step has been taken toward the solution of a very old and very perplexing problem of cell physiology. Here also should be mentioned the recent interesting study of fat absorption as related to the Golgi apparatus made by Cramer and Ludford ('25).

In non-glandular types of epithelia the Golgi apparatus is usually relatively inconspicuous and often more or less fragmented, except in cells undergoing keratinization. In such cells it has been shown by Deineka ('12), in the corneal epithelium, and by Cajal ('14), in the cells of the oesophageal-stomach junction (rabbit), that the apparatus undergoes a gradual, but very considerable increase in size, accompanied by fragmentation, during the keratinization of the cell. We know next to nothing as to the real origin of the keratin compounds in these cells, but the behavior of the Golgi apparatus and its known relation to synthetic processes in other cells suggests at least the possibility that in keratinization the Golgi material is again implicated, as a secretory center.

Turning now to connective tissues, we find that in the ordinary type of connective-tissue cell the Golgi apparatus occurs

frequently as a network of rather insignificant dimensions, exhibiting no features indicative of unusual activity (v. Bergen, '04, etc.). When such cells are converted into adipose tissue, Cajal ('14) has shown that the Golgi apparatus undergoes a process of fragmentation. His figures are not very detailed, but they suggest conditions strikingly similar to those which I have found in lipoid glands of many types. Whence the possibility is clearly indicated of tracing the derivation of fat to the same general processes which produce the lipoidal droplets in cells of the skin glands.

Extending our survey to connective-tissue cells occurring as cartilage cells, odontoblasts, and osteoblasts, we find that in them all the Golgi apparatus undergoes a process of hypertrophy associated with the activity of the cell, followed in some cases by regression coincident with functional depression. These features have been studied particularly by Pensa ('13), Cajal ('14), and Deineka ('16). Cajal's description of the odontoblasts is particularly pertinent, for he noted that the part of the cell directed toward the tooth substance was loaded with fine granules and vacuoles which seemed to be passing in a direction from Golgi apparatus to free surface. Deineka has described the direct activity of the Golgi apparatus during the calcification of the fundamental cartilage in intracartilaginous ossification. Here, too, should be noted the remarkable cycle of the Golgi apparatus in the lutein cells, as worked out by Riquier ('10).

At the present time these features cannot be vigorously pressed, for the matter has still to be examined more thoroughly; but the idea cannot be avoided that in connective-tissue cells, also, processes of an essentially secretory character are associated with the Golgi apparatus.

The occurrence of the Golgi apparatus in various kinds of blood corpuscles has been determined by numerous observers, and it is clear that it is always present except in such cells as the red corpuscles of mammals. It is usually rather small (v. Bergen, '04; Verson, '08; Cowdry, '21), and its relation to the numerous granules of white corpuscles or to haemo-

globin formation has not been especially examined. There seems at present to be no actual evidence upon which to base a reasonable explanation of the Golgi apparatus in blood, and nothing is to be gained just now by pure speculation.

The conditions in muscle tissue are rather obscure. In smooth-muscle cells, as noted by v. Bergen ('04) and others, the apparatus consists of a not very extensive network located at one pole of the somewhat elongate nucleus. Nothing is known concerning its behavior which suggests very much as to its function. In striated-muscle fibers the facts are of much greater interest, and I have recently summarized them in another place (Bowen, '26 c). The Golgi apparatus in striated muscle has been identified, still with some uncertainty, as an extraordinary network which invests the muscle fibrils in a more or less regularly developed system of transverse and longitudinal fibers. The most extensive researches on this Golgi network are those of Veratti ('02) and Holmgren ('08, '10, and '13). The latter's view of the apparatus as a canalicular system, which in the muscle fiber serves as a nutritive channel, seems no longer tenable, but the relations of the network to the so-called Q- and J-granules are of much interest. These granules or sarcosomes have long been known, particularly in insect muscles, where they may attain a remarkable development. They present many points in common with secretory granules, and I have elsewhere suggested (Bowen, '26 c) the possibility that they may actually represent materials associated on the one hand with the metabolic processes of muscular activity and on the other with the synthetic operations of the Golgi apparatus. Such a view is admittedly of a purely speculative character, but it at least suggests a possible angle of approaching the problem anew, while at the same time offering grounds of concrete comparison with the functional activity of the Golgi apparatus in other tissues.

There is finally the long-standing puzzle of what the Golgi apparatus finds to do in nerve cells. Here it was first discovered, is most easily demonstrated, and attains perhaps

its most extensive development. Two suggestions have been current for some time, though they seem only recently to have been published. One of these explains the scattered form of the Golgi apparatus, so common in many nerve cells, as an expression of the high degree of metabolism existing in these cells (Rau and Ludford, '25). But whether nerve cells, as compared with other cells, actually have a rate of metabolism commensurable with the amount or mode of distribution of the Golgi material present, seems highly doubtful in the light of current physiological considerations. The other suggestion is that the Golgi apparatus is involved in the production of the so-called Nissl substance (e.g., Brambell, '23). Assuming for the moment that the Nissl substance actually is a secretory product of the Golgi apparatus, several interesting relations find a ready explanation. Thus the intimate topographical relation between Nissl bodies and Golgi network, so clearly demonstrated by Marcora ('09), becomes readily explicable. That such relations do exist has been corroborated by several observers, notably Cajal ('14) on vertebrates and Poluszynski ('11) on Crustacea. These workers, together with Collin and Lucien ('09) and several others, have completely disproved the views of Legendre ('10) as to the identity of Golgi apparatus and Nissl substance. Marcora's conclusion to the same effect was still further supported by his proof ('12) that the Golgi apparatus antedates the appearance of Nissl substance in developing nerve cells. In addition, the distribution of Nissl and Golgi substances has been shown to be in general the same, with, however, some exceptions not yet very thoroughly examined. Finally, as first shown by Marcora ('10) and subsequently reexamined by Cajal ('14) and Penfield ('20), the Golgi apparatus undergoes characteristic changes of a progressive nature which coincide with the chromatolysis accompanying injury to a nerve fiber. The Golgi material indeed assumes in the affected cell a new distribution, which corresponds rather strikingly to that of the Nissl substance. Even more interesting is the behavior of the Golgi apparatus in cells

after prolonged stimulation, which, as is well known, produces very definite changes in the Nissl substance. Thus Legendre ('10) has shown that the apparatus in such stimulated cells presents a somewhat looser network which tends to lie only toward the periphery of the cell—in other words, it coincides with the new position assumed by the Nissl substance. Such a series of coincidences, to which, as a whole, attention has not before been directed, certainly points very strongly to the existence of some connection between Nissl substance and Golgi apparatus, and suggests that when our understanding of the former is more satisfactory, the significance of the latter in nerve cells may become clearer.

In concluding this hasty review of the Golgi apparatus in various tissues, certain very recent possibilities as to its significance in the Protozoa ought at least to be mentioned. Duboscq and Grassé ('24 and '25) have published a series of short papers in which they seek to establish an homology between the Golgi apparatus and the flagellate parabasal apparatus. This view does not agree very well with current guesses as to the nature of the parabasal bodies, but this in itself is perhaps of no great importance. The authors suggest that the parabasal body may be an accumulation of an 'energizing substance' consumed by the flagella for their functioning. A serious analysis of this whole viewpoint is as yet simply impossible. Of much greater interest is the conclusion tentatively suggested by Nasonov ('24 b and '25), that the Golgi apparatus is represented in Protozoa by the wall of the contractile vacuole. As to the facts observed by Nasonov there seems little room for question; they have, indeed, been corroborated by Young ('24) and Fauré-Fremiet ('25), but as to their interpretation in terms of the Golgi apparatus much skepticism has been expressed. This attitude of doubt seems to be reinforced by a recent paper by Hirschler ('25), who finds that slight changes in the usual osmic impregnation method result in a selective blackening of the nuclear membrane. I can corroborate this result, for a sharp demonstration of the nuclear membrane is not un-

common in certain gland cells after treatment by the method of Kolatchev. Such results lead one to suspect that the blackening of the wall of the contractile vacuole may be a similar technical freak, quite unrelated to the customary blackening of the Golgi apparatus. But granting the force of such criticisms, the findings of Nassonov ('25) in his second paper seem very difficult to get around. Here he figures in *Dogielella* a typical Golgi network which does not form the wall of the contractile vacuole, but rather encircles it like a Saturn's ring. His observations on *Chilodon* suggest the further possibility that a close association of the Golgi apparatus with the contractile vacuole may be a purely secondary modification—a result which would certainly make it easier to understand the presence of the Golgi material in Protozoa which lack a contractile vacuole. On the whole, it would seem wise to avoid drawing any conclusion for the present, rather to admit frankly the interesting possibilities which Nassonov has suggested and to give the whole problem a thorough and unprejudiced examination.

What, then, is the significance of the Golgi apparatus stated in terms of its function as a generalized cell organ? In the first place, it seems clear that this structure does not itself become transformed into various products of differentiation, as was once so widely claimed for the mitochondria. Thus its substance appears as a relatively stable part of the protoplasm which, it is fairly certain, must operate in accord with the 'process theory' of metabolism as opposed to the old views of Liebig, Pflueger, and Verworn—as, indeed, was long ago hinted by Weigl ('12). Furthermore, we find the Golgi apparatus undergoing changes of position, size, and topography which distinguish it sharply from the rather inert mitochondria and distinctly point to its immediate participation in the common operations of living matter. Hence has arisen the oft-expressed belief that the Golgi apparatus is intimately involved in cell metabolism. Now we find it particularly active in cells which are differentiating products that are not to become a permanent part of the cell system. Thus, secre-

tory granules, yolk, the aërosome, materials for bone and tooth, etc., are all products whose tenure of life in the cell is brief, although, as in the case of yolk, the substance may once more lose itself in the cytoplasm just as in the case of any other food material. This possible activity of the Golgi apparatus as a synthetic center, more particularly its probable rôle in the production of enzymes as expressed in many kinds of 'zymogen' granules, suggests the further possibility that the Golgi apparatus may be the real center of formation for enzymes in general. Thus might be explained its constant occurrence in cells of all kinds, while in those in which certain types of synthetic activity are emphasized, the apparatus is increased in size and reshaped to the exigencies of the occasion. The Golgi apparatus would appear to be the synthetic center wherein are built up primarily those cellular products which in the broadest sense of the term may be classified as secretions, including, therefore, some things which ordinarily pass under the name of excretions. Indeed, although the possibilities have as yet been scarcely examined, the process of excretion, in so far as it is of a secretory character, may likewise fall within the province of the Golgi apparatus, as indicated particularly in the Protozoa, and this aspect of the general functional significance of the Golgi apparatus has been especially developed by Nassonov ('24 b). Such a tentative conclusion, it seems to me, is justified by the available data, and beyond it we are not in position as yet even to speculate. We must now wait until the evidence disproves or overtakes our theories. At the very least, we have an interesting signpost on the road to progress.

LITERATURE CITED

- ALLEN, C. E. 1917 The spermatogenesis of *Polytrichum juniperinum*. *Ann. Bot.*, vol. 31.
- AVEL, M. 1925 Sur les propriétés physiques de l'appareil de Golgi. *C. R. Soc. Biol.*, T. 93.
- BALLOWITZ, E. 1900 a Ueber das Epithel der Membrana elastica posterior des Auges. *Arch. f. mik. Anat.*, Bd. 56.
- 1900 b Eine Bemerkung zu dem von Golgi und seinen Schuelern beschriebenen 'Apparato reticolare interno.' *Anat. Anz.*, Bd. 18.

- BARINETTI, C. 1912 L'apparato reticolare interno e la centrosfera nelle cellule di alcuni tessuti. *Boll. Soc. Med.-Chir. di Pavia*.
- BENSLEY, R. R. 1910 On the nature of the canalicular apparatus of animal cells. *Biol. Bull.*, vol. 19.
- VON BERGEN, F. 1904 Zur Kenntnis gewisser Strukturbilder. *Arch. f. mik. Anat.*, Bd. 64.
- BOWEN, R. H. 1920 Studies on insect spermatogenesis. I. Hemiptera. *Biol. Bull.*, vol. 39.
- 1922 On the idiosome, Golgi apparatus, and acrosome. *Anat. Rec.*, vol. 24.
- 1924 a On the acrosome of the animal sperm. *Anat. Rec.*, vol. 28.
- 1924 b On a possible relation between the Golgi apparatus and secretory products. *Am. Jour. Anat.*, vol. 33.
- 1925 a Studies on the Golgi apparatus in gland cells. I. *Quart. Jour. Mic. Sci.* (In press.)
- 1925 b Studies. II. *Ibid.*
- 1926 a Studies. III. *Ibid.*
- 1926 b Studies. IV. *Ibid.*
- 1926 c Notes on the form and function of the Golgi apparatus in striated muscle. *Biol. Bull.*, vol. 50.
- BRAMBELL, F. W. R. 1923 The activity of the Golgi apparatus in neurones of *Helix aspersa*. *Jour. Physiol.*, vol. 57.
- 1924 The nature and origin of yolk. *Brit. Jour. Exp. Biol.*, vol. 1.
- 1925 The part played by the Golgi apparatus in secretion. *Jour. Roy. Mic. Soc.*
- CAJAL, R. Y 1914 Algunas variaciones fisiológicas y patológicas del aparato reticular de Golgi. *Trab. Lab. inv. Madrid*, vol. 12.
- CATTANEO, D. 1914 Ricerche sulla struttura dell'ovario dei mammiferi. *Arch. ital. Anat. e Emb.*, vol. 12.
- COLLIN, R., ET LUCIEN, M. 1909 Sur les rapports du réseau interne de Golgi et des corps de Nissl. *Bib. Anat.*, T. 19.
- COWDRY, E. V. 1921 The reticular material of developing blood cells. *Jour. Exp. Med.*, vol. 33.
- 1924 General cytology. Chicago.
- CRAMER, W., AND LUDFORD, R. J. 1925 On cellular changes in intestinal fat absorption. *Jour. Phys.*, vol. 60.
- DA FANO, C. 1922 On Golgi's internal apparatus in different physiological conditions of the mammary gland. *Jour. Phys.*, vol. 56.
- DEINEKA, D. 1912 Der Netzapparat von Golgi in einigen Epithel- und Bindegewebszellen. *Anat. Anz.*, Bd. 41.
- 1916 Developpement des cellules osseuses. *Arch. Russ. d'Anat., Hist., et Emb.*, vol. 1.
- DREW, A. H. 1920 Preliminary tests on the homologue of the Golgi apparatus in plants. *Jour. Roy. Mic. Soc.*
- DUBOSQ, O., ET GRASSÉ, P. 1924 Notes sur les protistes parasites des termites de France. *C. R. Soc. Biol.*, T. 90.
- 1925 *Ibid.*, pp. 154-156 and 345-348.
- 1925 L'appareil parabasal des flagellés et sa signification. *C. R. Acad. Sci.*, T. 180.

- DUESBERG, J. 1912 Plastosomen, 'Apparato reticolare interno' und Chromidial-apparat. *Anat. Hefte*, Bd. 20.
- 1914 Trophospongien und Golgischer Binnenapparat. *Erg. zum Bd. 46, Anat. Anz.*
- FAURÉ-FREMIET, E. 1925 La structure permanente de l'appareil excréteur. *C. R. Soc. Biol.*, T. 93.
- FLEMMING, W. 1896 Zelle. *Anat. Hefte*, Bd. 6.
- FUCHS, H. 1904 Ueber Beobachtungen an Sekret- und Flimmerzellen. *Anat. Hefte*, Bd. 25.
- GATENBY, J. B., AND WOODGER, J. H. 1920 On the relationship between the formation of yolk and Golgi apparatus. *Jour. Roy. Mic. Soc.*
- GUILLIERMOND, A. 1920 Sur l'origine des vacuoles dans les cellules de quelques racines. *C. R. Soc. Biol.*, T. 83.
- 1924 Nouvelles recherches sur les constituants morphologiques du cytoplasme de la cellule végétale. *Arch. d'Anat. mic.*, T. 20.
- GUILLIERMOND, A., AND MANGENOT, G. 1922 Sur la signification de l'appareil réticulaire de Golgi. *C. R. Acad. Sci.*, T. 174.
- HARVEY, L. A. 1925 a On the relation of the mitochondria and Golgi apparatus to yolk-formation. *Quart. Jour. Mic. Sci.*, vol. 69.
- 1925 b On the form and function of the Golgi apparatus. *Science Progress*, no. 76.
- HIRSCHLER, J. 1913 Ueber die Plasmastrukturen in den Geschlechtszellen fuer Ascariden. *Arch. f. Zellforsch.*, Bd. 9.
- 1916 Ueber die Plasmakomponenten der weiblichen Geschlechtszellen. *Arch. f. mik. Anat.*, Bd. 89.
- 1918 Ueber den Golgischen Apparat embryonaler Zellen. *Ibid.*, Bd. 91.
- 1925 Sur une certaine ressemblance entre le noyau cellulaire, l'appareil de Golgi et les mitochondries. *C. R. Soc. Biol.*, T. 93.
- HOLMGREN, E. 1903 Weiteres ueber die Trophospongien verschiedener Druesenzellen. *Anat. Anz.*, Bd. 23.
- 1908 Ueber die Trophospongien der quergestreiften Muskelfasern. *Arch. f. mik. Anat.*, Bd. 71.
- 1910 Untersuchungen ueber die Umsetzungen der quergestreiften Muskelfasern. *Arch. f. mik. Anat.*, Bd. 75.
- 1913 Von den Q und J Koernern der quergestreiften Muskelfasern. *Anat. Anz.*, Bd. 44.
- KARPOVA, L. 1925 Beobachtungen ueber den Apparat Golgi in den Samenzellen. *Zeitsch. f. Zellforsch. u. mik. Anat.*, Bd. 2.
- LEGENDRE, R. 1910 Recherches sur le réseau interne de Golgi. *Anat. Anz.*, Bd. 36.
- LEVI, G. 1919 Nuovi studii su cellule coltivate 'in vitro.' *Arch. ital. Anat. e Emb.*, vol. 16.
- LUDFORD, R. J. 1921 Contributions to the study of the oogenesis of Patella. *Jour. Roy. Mic. Soc.*
- 1925 a Cell organs during secretion in the epididymis. *Proc. Roy. Soc., B*, vol. 98.
- 1925 b The cytology of tar tumours. *Ibid.*

- LUNDEGÅRD, H. 1910 Ein Beitrag zur Kritik zweier Vererbungshypothesen. *Jahrb. f. wiss. Bot.*, Bd. 48.
- MARCORA, F. 1909 Sui rapporti tra apparato reticolare interno e corpi di Nissl. *Boll. Soc. Med.-Chir. Pavia*.
- 1910 Sulle alterazioni dell'apparato reticolare interno nelle cellule nervose. *Arch. ital. de Biol.*, vol. 53.
- 1912 L'istogenesi del sistema nervosa centrale. *Boll. Soc. Med.-Chir. Pavia*.
- MEVES, F. 1896 Zellteilung. *Anat. Hefte.*, Bd. 6.
- 1917 Historisch-Kritische Untersuchungen ueber die Plastosomen der Pflanzenzellen. *Arch. f. mik. Anat.*, Bd. 89.
- MORELLE, J. 1924 La substance de Golgi dans les cellules pancréatiques. *Soc. belge de Biol.*, T. 91.
- 1925 La substance de Golgi dans les cellules du pancréas. *Ann. d. l. Soc. sci. de Bruxelles*, T. 44.
- MOTTIER, D. M. 1918 Chondriosomes and the primordia of chloroplasts and leucoplasts. *Ann. Botany*, vol. 32.
- NASSONOV, D. 1918 Recherches cytologiques sur les cellules végétales. *Arch. Russ. d'Anat. Hist. et Emb.*, T. 2.
- 1923 Das Golgische Binnennetz und seine Beziehungen zu der Sekretion. *Amphibiendruesen. Arch. f. mik. Anat.*, vol. 97.
- 1924 a Ibid. (Fortsetzung.) *Ibid.*, Bd. 100.
- 1924 b Der Exkretionsapparat der Protozoa als Homologon des Golgischen Apparats der Metazoozellen. *Ibid.*, Bd. 103.
- 1925 Zur Frage ueber den Bau und die Bedeutung des lipoiden Excretionsapparates bei Protozoa. *Zeitsch. f. Zellforsch. u. mik. Anat.*, Bd. 2.
- NATH, V. 1924 Oogenesis of *Lithobius forficatus*. *Proc. Cambridge Phil. Soc.*, vol. 1.
- 1925 Cell inclusions in the oogenesis of scorpions. *Proc. Roy. Soc., B*, vol. 98.
- PARAT, M., ET PAINLEVÉ, J. 1924 Observation vitale d'une cellule glandulaire en activité. *C. R. Ac. Sci.*, T. 179.
- 1924 Appareil réticulaire interne de Golgi, trophosponge de Holmgren et vacuome. *Ibid.*
- 1925 See papers in *C. R. Soc. Biol.*, etc.
- PENFIELD, W. G. 1920 Alterations of the Golgi apparatus in nerve cells. *Brain*, vol. 43.
- PENSA, A. 1912 Osservazioni di morfologia e di biologia cellulare nei vegetali. *Arch. f. Zellforsch.*, Bd. 8.
- 1913 La struttura della cellula cartilaginea. *Ibid.*, T. 11.
- 1917 Fatti e considerazioni a proposito de alcune formazioni endocellulari dei vegetali. *Mem. Ist. Lomb. sc. e lett. Cl. di sc.*, vol. 22.
- 1919 Osservazioni di morfologia e biologia cellulare. *Monit. Zool. Ital.*, vol. 30.
- POLUSZYNSKI, G. 1911 Untersuchungen ueber den Golgi-Kopsch'schen Apparat in den Ganglienzellen der Krustaceen. *Bull. d. Akad. Sci. Cracovie*.
- RAU, A. S., AND LUDFORD, R. J. 1925 Variations in the form of the Golgi bodies during the development of neurones. *Quart. Jour. Mic. Sci.*, vol. 69.

- RIQUIER, J. K. 1910 Der innere Netzapparat in den Zellen des Corpus luteum. Arch. f. mik. Anat., Bd. 75.
- SANCHEZ, S. Y 1922 Sur la nature et la fonction de l'appareil réticulaire de Golgi. C. R. Acad. Sci., T. 175.
- VERATTI, E. 1902 Ricerche sulla fine struttura della fibra muscolare striata. Mem. del reale Ist. Lomb. di sci. e lett., vol. 19.
- VERSON, S. 1908 Contributo allo studio delle cellule giganti tubercolari e di altri elementi cellulari. Arch. per le Sci. med., vol. 32.
- VOINOV, D. 1925 Les elements sexuels di Gryllotalpa vulgaris Latr. Arch. de Zool. exp. et gén., T. 63.
- WEIGL, R. 1912 Untersuchungen ueber den Golgi-Kopsch'schen Apparat. Bull. Acad. Sci. Cracovie.
- WILSON, E. B. 1925 a The cell in development and heredity. 3rd ed. New York.
- 1925 b Protoplasmic systems and genetic continuity. Am. Nat., vol. 59.
- YOUNG, R. A. 1924 On the excretory apparatus in Paramecium. Science, vol. 60.
- ZIMMERMANN, K. W. 1898 Beitrage zur Kenntniss einiger Druesen und Epithelien. Arch. f. mik. Anat., Bd. 52.

PROFESSEUR OMER VAN DER STRICHT

Lorsque le Professeur Omer van der Stricht eut terminé sa leçon, le 31 janvier 1924 et que, légèrement indisposé, il eut quitté l'Institut d'Anatomie, il ne se rendait pas compte de la gravité de son état de santé. Pendant vingt-cinq ans il avait donné cours sans avoir jamais dû interrompre son travail pour cause de maladie. Sa constitution particulièrement robuste ignorait ces petites misères de la vie quotidienne: aussi, après s'être résigné à subir des soins médicaux pendant une dizaine de jours, se crut-il en état de reprendre ses leçons. Les vifs applaudissements avec lesquels les étudiants saluèrent son arrivée dans le grand Auditoire, lui firent cependant une impression pénible: il m'avoua avec mélancolie que ces applaudissements convenaient à la fin de l'année académique et qu'alors cet hommage lui était agréable, mais que cette manifestation cordiale à l'occasion de son retour peut-être trop rapide, lui semblait prématurée et lui laissait l'impression qu'il venait de donner son dernier cours. Ce pressentiment devint, hélas! une triste réalité: une pleurésie terrassa l'estimé Professeur qui s'éteignit après de longues souffrances, à Menton, le 8 mai 1925.

Ecrire une biographie de O. van der Stricht constitue pour moi, son élève et son successeur, une tâche qui m'est facilitée par une collaboration journalière d'un quart de siècle; émettre un jugement sur son oeuvre scientifique me fournit en même temps l'occasion d'apporter un hommage public et bien mérité à un ami et un maître regretté.

Omer van der Stricht, le dernier-né d'une nombreuse famille, naquit à Dickelvenne le 23 mai 1862. Après avoir fait ses humanités d'abord au Collège d'Audenarde, puis à celui de St. Nicolas, il fit de brillantes études en médecine à

l'Université de Gand et obtint avec la plus grande distinction le diplôme de docteur en médecine, chirurgie et accouchements, en 1888. Il recueillit de nombreux prix dans des concours universitaires et académiques, obtint en 1889 une bourse de voyage à la suite d'un mémoire sur le Cartilage articulaire des Oiseaux et visita pendant deux ans les Laboratoires de Paris, Kiel, Würzburg et Vienne. Un travail sur le développement du sang dans le foie embryonnaire lui valut le 1er prix au concours Universitaire de 1890. L'Académie royale de Médecine lui décerna une série de récompenses : en 1891, pour un mémoire sur l'origine des globules blancs et rouges ; en 1894, pour une étude sur la pathogénie et le traitement de l'épilepsie (en collaboration avec le Dr. A. Claus) ; en 1896, pour ses recherches sur le système nerveux de l'Amphioxus (en collaboration avec le Dr. Heymans).

La carrière scientifique de O. van der Stricht à l'Université de Gand débuta en 1884, alors qu'il était encore étudiant. Le 7 juin 1884, il fut nommé préparateur du cours d'Histologie ; le 8 mars 1889, assistant et le 20 septembre 1894, chef des travaux d'anatomie macroscopique et microscopique. Le 19 octobre 1899 il succéda au Professeur Ch. Van Bambeke comme chargé des cours d'histologie générale et spéciale et d'embryologie, fut nommé professeur extraordinaire, le 8 octobre 1901 et ordinaire le 25 octobre 1906.

Pendant la guerre mondiale, il lui fut impossible, après l'invasion des Allemands à Gand, de rester plus longtemps dans sa patrie opprimée et de renoncer à son activité universitaire—le seul but de sa vie.

Il partit pour les Etats-Unis d'Amérique et y fut nommé Fellow in Biology à la Western Reserve University de Cleveland (Ohio), pendant les années 1915-1916 et 1916-1917, pour exercer ensuite les fonctions de Lecturer in Biology à la Johns Hopkins Medical School de Baltimore, pendant 1917-1918.

Il devint membre de l'Académie royale de Médecine en 1895 et de la Classe des Sciences en 1919, membre correspondant de la Zoological Society de Londres en 1922, membre du

Conseil de perfectionnement pour l'Enseignement supérieur pour la période 1924-1926, et était membre et trésorier de la Société de Médecine de Gand, et membre de la Société des Sciences médicales et naturelles de Bruxelles.

Chevalier de l'Ordre de Léopold en 1910, officier en 1919, O. van der Stricht reçut la Croix Civique de Ire Classe en 1922 et fut nommé Chevalier de la Légion d'Honneur en 1922.

Par ses nombreuses publications, O. van der Stricht a conquis une des premières places parmi les biologistes belges; par son enseignement remarquable, il s'est montré digne de son maître Ch. Van Bambeke, auquel il succéda d'ailleurs, en 1911, comme directeur des célèbres Archives de Biologie.

Au début de son activité scientifique, il a publié le résultat de ses recherches dans le domaine de l'Anatomie pathologique, après une étude approfondie des tissus normaux. L'étude de la genèse et de la structure des cellules sanguines l'amena à examiner ces éléments dans la leucémie; après l'examen du rein normal, il étudia cet organe, gravement atteint en cas de choléra ou après extirpation de l'un des reins. Il attira l'attention des savants sur les lésions microscopiques provoquées dans l'organisme par l'anémie pernicieuse progressive, l'hématomyélie, l'épilepsie, la peste.

Depuis le moment où il fut chargé des cours d'Histologie et d'Embryologie, il se consacra exclusivement à l'étude des tissus normaux et de l'embryogenèse normale. Ce fut principalement à l'examen de la cellule-oeuf, pendant la période qui précède et suit la fécondation, qu'il appliqua ses qualités extraordinaires d'observateur perspicace; son habileté technique marchait de pair avec une patience inépuisable et une persévérance digne d'admiration. Il confectionna des milliers de préparations avec un soin méticuleux et infatigable, et la collection qu'il rassembla est connue et appréciée dans le monde entier par ses collègues spécialistes.

Il étudia les oeufs de l'Amphioxus, d'une planaire marine (Thysanozoon), de certains échinodermes, de l'araignée domestique, de la femme, de la chauve-souris, de la chienne.

Il stimulait sans cesse ses élèves à exploiter l'immense champ embryologique et son expérience nous servait alors admirablement dans l'étude de l'oeuf de nombreux autres animaux: grenouille, poissons, mollusques, la souris, le chat, le cobaye, etc.

L'étude si difficile de l'oeuf des mammifères l'occupa pendant des années et pour donner suite au voeu de ses collègues, d'avoir une idée générale de ses propres recherches et de celles de ses élèves, dans ce domaine intéressant, au Laboratoire d'Histologie de l'Université, il saisit l'occasion du Congrès des Anatomistes à Gand, en 1922, pour faire une étude d'ensemble de l'ovogenèse comparée chez les Mammifères. Cet ouvrage fondamental, qui parut plus tard richement illustré dans les Archives de Biologie, fut son chant du cygne: il faut le considérer comme son testament scientifique.

On ne peut également point passer sous silence ses recherches remarquables sur le système nerveux de l'Amphioxus et la structure microscopique de l'oeil, du neuroépithélium olfactif et de l'oreille interne, ainsi que du muscle cardiaque humain, ces deux derniers travaux, en anglais, ayant été faits et publiés en Amérique.

Estimé par les étudiants qui appréciaient vivement la clarté de son enseignement, honoré par ses collègues qui ne venaient jamais en vain lui demander secours et conseil, aimé de ses amis pour sa cordiale hospitalité, le Professeur Dr. O. van der Stricht voua son existence au travail purement scientifique: que sa vie serve d'exemple aux générations futures et que son souvenir reste gravé, durable et salubre, dans la mémoire des générations présentes.

PROF. DR. H. LAMS.